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Erratum

Listed below is a correction to a manuscript which was previously published in the Transactions of the Illinois State Academy of Science. The correction is printed on the following un-numbered page for easy insertion into the original manuscript.

Stoynoff, Nick A. 1993. A quantitative analysis of the vegetation of Bluff Spring Fen Nature Preserve. Trans. Ill. State Acad. Sci. 86 (3&4): 93-110.

Correction to Table 3: insertion of 3 lines at top of tabular material.

Table 3. Importance values for the vascular plants of the calcareous seep.

Species	Importance Value	Relative Frequency	Relative Cover
Eleocharis rostellata	52.9	12.4	40.5
Potentilla fruticosa	23.0	8.1	14.9
Solidago ohioensis	15.2	8.1	7.1
Carex stricta	10.6	5.0	5.6
Deschampsia cespitosa	9.1	4.6	4.5
Rhyncospora capillacea	8.7	4.6	4.1
Lobelia kalmii	8.3	7.7	0.6
Sorghastrum nutans	7.0	2.3	4.7
Silphium terebinthinaceum	6.5	3.9	2.6
Cladium mariscoides	6.4	4.6	1.8
Solidago uliginosa	6.3	4.6	1.7
Valeriana edulis	3.3	1.9	1.4
Parnassia glauca	3.2	2.3	0.9
Scleria verticillata	3.0	1.5	1.5
Eleocharis tenuis	2.5	1.9	0.6
Juncus brachycephalus	2.4	2.3	0.1
Carex sterilis	2.1	1.6	0.5
Rudbeckia hirta	2.1	1.2	0.9

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Premodern *Pleurobema rubrum* (Rafinesque 1820) from the Illinois River

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ABSTRACT

Premodern specimens of *Pleurobema rubrum* (Rafinesque 1820) from several sites in west–central Illinois confirm the former existence of this freshwater mussel (Mollusca: Bivalvia: Unionidae) in the Illinois River. Two subfossil specimens of *P. rubrum* were recovered from channel sediments of the Illinois River in Mason County. The species also comprises 1.1% of the identified mussel assemblage in a collection of redeposited prehistoric shells from Fulton County. *Pleurobema rubrum* appears to have been a subdominant species in the central reaches of the Illinois River during prehistoric and early–historic times. Its apparent extirpation during the first few decades of the 20th century may have been caused by pollution, siltation, and commercial development of the stream.

INTRODUCTION

William C. Starrett collected more than 4,200 live freshwater mussels during his 1966 mussel survey of the Illinois River (Starrett 1971). None of Starrett's 429 collections yielded any live specimens of the so–called *Pleurobema cordatum* complex, which consists of four species in the eastern Mississippi River basin: *Pleurobema coccineum* (Conrad 1834), *P. cordatum* (Rafinesque 1820), *P. plenum* (Lea 1840), and *P. rubrum* (Rafinesque 1820; =*P. pyramidatum* [Lea 1840]; Cummings and Mayer 1992). However, Starrett did report that two species of the *P. cordatum* complex had lived in the Illinois River in the past. *Pleurobema coccineum* was represented in several early museum collections and in four deposits of old shells located along the banks of the river (Starrett 1971). The only record of *P. rubrum* in the river was a pre–1900 collection housed at the Ohio State Museum (OSM 19230), although questions surround this record because it lacks specific locality data (Starrett 1971). This paper reports recent collections of premodern shells from the Illinois River near Havana, Illinois, which confirm the former existence of *P. rubrum* in the Illinois River.

MATERIALS AND METHODS

Premodern unionid mussel shells were recovered in 1991 from two locations in the middle reaches of the Illinois River. The first is near the left (east) bank of the river in Mason County, Illinois, just downstream from Grand Island and the re–entrant channel of Bath

Chute (40°09'08"N, 90°12'11"W; 171.7 km [106.7 mi] above mouth of Illinois River). An extensive bed of mussel shell intermixed with some prehistoric artifacts covers the beach at this location (True Temper archaeological site; 11MN288), but it has not been sampled. The collections reported here were taken from the bed of the river adjacent to the site at depths of about 1.0–1.3 m.

The second location is an archaeological deposit named the Nancy's Point site (11F2758), which is located on the right (west) bank of the Illinois River in Fulton County, Illinois (40°20'40"N, 90°03'11"W; 198.6 km [123.4 mi] above mouth of Illinois River). The site consists of an extensive bed of shell that runs along the beach and covers a low natural levee west of the shoreline. The deposit contains bivalve shell (Unionidae and Sphaeridae), gastropod shell, sand, and some prehistoric artifacts. The artifact assemblage is rather specialized, with a number of crude net weights occurring in association with the shell. Temporally diagnostic artifacts tend to occur along the shoreline and may or may not be associated with the shell. They date primarily to the Early Woodland period of about 2550–2100 years B.P. (contracting–stemmed projectile points and Marion Thick, Black Sand, and Morton ceramics), although several specimens associated with the younger Mississippian and Oneota cultures are also represented (Esarey 1990).

The sample of shell from the Nancy's Point site was recovered from three 1 m^2 collection units (CU 1–3), from which all "unconsolidated" shell and other material were removed and transported to the laboratory for processing and analysis. Excavations continued downward into the deposit to the point where shells became embedded in a sand matrix, at which point the collection terminated. CU–1 was located on a sloping beach about halfway between the shoreline and the crest of the natural levee; CU–2 was located on the crest of the natural levee about 20 m northwest of CU–1; CU–3 was located on the crest of the levee about 20 m north of CU–2. After shells had been removed from CU–1, the unit was excavated to a depth of about 1 m to expose a sediment profile.

The specimens reported here include unionid mussels recovered from the Illinois River channel adjacent to the True Temper site and from the three collection units at the Nancy's Point site. Shells were identified at the Illinois State Museum using comparative materials from the museum's scientific collections. All specimens have been deposited at the Illinois State Museum.

For the purposes of this analysis, "identifiable" shells were defined as specimens that retained the beak or umbo portion of the shell in the vicinity of the pseudocardinal teeth, regardless of whether or not they could be identified below the family level. This criterion minimized the chances that fragmentary specimens would be counted more than once. All specimens lacking the beak or umbo portion of the shell were considered "unidentifiable." The counts or frequencies of identifiable specimens reported here represent numbers of identified specimens (NISP). Taxonomic nomenclature follows Turgeon and others (1988), except for revisions to the Anodontinae proposed by Hoeh (1990). Also, the nomenclature change from *Pleurobema pyramidatum* (Lea 1840) to *Pleurobema rubrum* (Rafinesque 1820) follows Johnson and Baker's (1973) selection of a lectotype for the latter species.

RESULTS

True Temper Site Locality

Several dead shells and a number of live mussels were collected from the bed of the Illinois River adjacent to the True Temper site. The dead shells occurred as pairs of closed valves joined by the dorsal hinge ligament. They were embedded in a silty substrate in life position, with the posterior–dorsal margins of the valves protruding above the river bed. Five species of dead shells were observed: *Amblema plicata* (Say 1817), *Arcidens confragosus* (Say 1829), *Fusconaia ebena* (Lea 1831), *Pleurobema rubrum*, and *Quadrula pustulosa* (Lea 1831). I collected one specimen of *F. ebena* and two of *P. rubrum*, neither of which has been collected live in the middle reaches of the Illinois River since 1912 (Forbes and Richardson 1913). All specimens are complete and in good condition. The proteinaceous periostracums and hinge ligaments are intact. However, the nacreous inner layer of shell is leached and somewhat chalky, suggesting that the shells had been exposed to dilute acids for an extended time after death occurred.

I also observed seven species of live mussels in the area. The most abundant, with 15 individuals, was *Amblema plicata*. This mussel was also the dominant species in this section of the river during Starrett's 1966 survey (Starrett 1971). The other species included 2 specimens of *Lasmigona complanata* (Barnes 1823), 7 specimens of *Leptodea fragilis* (Rafinesque 1820), 1 specimen of *Megalonaias nervosa* (Rafinesque 1820), 5 specimens of *Potamilus alatus* (Say 1817), 3 specimens of *Pyganodon grandis* (Say 1829), and 5 specimens of *Quadrula quadrula* (Rafinesque 1820).

The depositional history of the dead shell at this locality is suggested by the orientation of the valves and the historical changes in the species composition of unionid mussels in the Illinois River. The fact that shells were paired and oriented in life position indicates they died in place and had not been redeposited. The presence of two species that have not been observed alive in this section of the river for at least the past 80 years suggests the mussels may have died during or before the first few decades of the 20th century.

Nancy's Point Site

The three collection units at the Nancy's Point site yielded a total of 1,823 identifiable valves, 86% of which were identified to genus or species (Table 1). Twenty–eight species are represented. The predominant species is *Elliptio dilatata* (Rafinesque 1820), which comprises 62.6% of the total sample. *Pleurobema rubrum* is represented by 17 specimens and comprises 1.1% of the sample. *Pleurobema coccineum* is also represented, but is somewhat less abundant overall than *P. rubrum*.

The taphonomic history of Nancy's Point is indicated by the stratigraphy of the deposit and by the associations, condition, and distribution of the shell. First, a number of net–weight artifacts have been found in association with the shell. This suggests the shells were deposited by prehistoric people, although none of the shells appear to have been modified for use as artifacts. Second, consistent with the hypothesis of anthropic origin is the fact that 14.0% of the shells from CU–1 are medium to dark gray in color and one specimen is charred, presumably because of exposure to an artificial source of heat. Charred and discolored shells are common in archaeological assemblages, as mussels were often baked or steamed during food preparation or incidentally exposed to fire. Third, the

distribution of shell at the site suggests the entire assemblage has been redeposited. The western margin of the deposit is scalloped in plan view, as if the shell had been dumped on the surface in a series of loads that splayed out across the levee from east to west. Finally, the stratigraphic profile shows that several thin surface horizons, which together are 40 cm thick, disconformably overlie a massive brown silt comprising the natural levee. Horizon 1 is a surficial deposit of shell (bivalves and gastropods) and some sand (0–15 cm depth); Horizon 2 is a thin deposit of sand and some silt (15–20 cm depth); Horizon 3 consists of shell and some sand (20–30 cm depth); Horizon 4 is a finely bedded brown silt and yellowish sand that has deformed to convoluted bedding planes and an abrupt, irregular contact with the underlying horizon (30–40 cm depth); Horizon 5 is a massive, dark brown silt that grades downward to a lighter–colored silt with oxidation stains (>40 cm depth). Window glass recovered from the base of Horizon 4 indicates that everything above the basal silt was deposited historically. These observations suggest the shell component at the Nancy's Point site is redeposited dredge spoil that was removed historically from the Illinois River channel and deposited on the beach and natural levee along the west bank. The spoil consists primarily of shell and sand from a prehistoric deposit that is submerged beneath the river east of the current shoreline. Although the shells have been redeposited, they are probably representative of the unionid mussel species that occurred in this section of the river prehistorically.

Description of *Pleurobema rubrum*

The shells of *Pleurobema rubrum* from the True Temper locality are nearly complete (Figure 1). One measures 70.6 mm in length, 50.7 mm in height, and 40.9 mm in breadth (ISM 680132); the other is 83.1 mm in length, 57.9 mm in height, and 49.0 mm in breadth (ISM 680133). The shells are thick, moderately inflated, elongate, and obtuse triangular in outline. The anterior margin is somewhat flattened or truncated; the posterior margin is bluntly pointed. Dorsal and ventral margins are curved. The umbos are high, strongly directed forward, and anterior to the remainder of the shell. Beak sculpture consists of 2–3 concentric ridges near the end of the beak and 1–2 tubercles on the posterior ridge. There is a shallow radial sulcus beneath the posterior ridge. The periostracum is light to dark brown. Pseudocardinal teeth are large; lateral teeth are heavy and slightly curved. Beak cavities are shallow (older specimen) to moderately deep (younger specimen). The nacre is white to light gray, but coloration may have been leached by submersion.

The *Pleurobema rubrum* shells differ from *P. coccineum* in that their outlines are more obtuse, their anterior margins are less rounded, their beaks are directed anteriorly rather than apposed, and their radial sulcuses are more distinctive (see Stansbery 1983). *Pleurobema rubrum* is very similar to *P. coccineum* f. *mississippiensis* (Baker 1928) from the Mississippi River in Wisconsin, although the shell of the latter is less elongate and has a shallower beak cavity (Baker 1928:121–123).

DISCUSSION AND CONCLUSIONS

Specimens of *Pleurobema rubrum* from the True Temper and Nancy's Point sites confirm that this species inhabited the middle reaches of the Illinois River prior to modern times. Prehistoric specimens from the Nancy's Point site are probably redeposited food remains that may or may not be associated with the site's Early Woodland occupation. They

indicate that *P. rubrum* was a subdominant element of the Illinois River mussel fauna during prehistory.

The True Temper specimens appear to be part of a subfossil mussel bed that died and was preserved in place in the channel of the Illinois River, perhaps during the current century. Confirmed specimens of *Pleurobema rubrum* have not been collected from the river since before 1900, and *Fusconaia ebena*, a species found with it at True Temper, has not been seen alive in the middle reaches of the river since 1912. The extirpation of *P. rubrum* and *F. ebena* from this section of the river probably occurred before 1924, when Richardson (1928:457) failed to collect either species in Peoria Lake. The disappearance may have been part of a massive, progressive mussel die–off caused by the diversion of untreated Chicago sewage and industrial wastes into the Des Plaines and Illinois rivers after the opening of the Chicago Sanitary and Ship Canal in 1900. The mussel population of the lower Des Plaines River had been destroyed by 1908 (Wilson and Clark 1912), and in 1912 mussels were absent or on the decline in the upper section of the Illinois River near Morris, Ottawa, and Starved Rock (Forbes and Richardson 1913). The effects of pollution soon moved downstream into the middle section of the river, where Richardson (1925, 1928) documented a drastic decline in the abundance and diversity of mussel populations between 1912 and 1920. The expiration of the True Temper mussel bed may have occurred during this period, although independent radiometric evidence would be needed to confirm the date. If the True Temper specimens are evidence that *P. rubrum* lived in the Illinois River historically, the known range of this species in Illinois should be expanded beyond its mapped distribution in the Wabash and lower Ohio rivers in the eastern and southern parts of the state (cf. Cummings 1991a; Cummings and Mayer 1992:65).

The historical extirpation of *Pleurobema rubrum* from the Illinois River was part of a major decline in the biodiversity of unionid mussels in the river. Counting *P. rubrum*, there has been a 52% decrease in the number of mussel species living in the Illinois River—down from 48 species prior to 1960 to only 23 species since 1960 (cf. Cummings 1991b). The decline was probably caused by such factors as pollution, siltation, and commercial development of the stream (Cummings 1994). Shells from archaeological and geological deposits may be used to better define the extent and severity of these changes.

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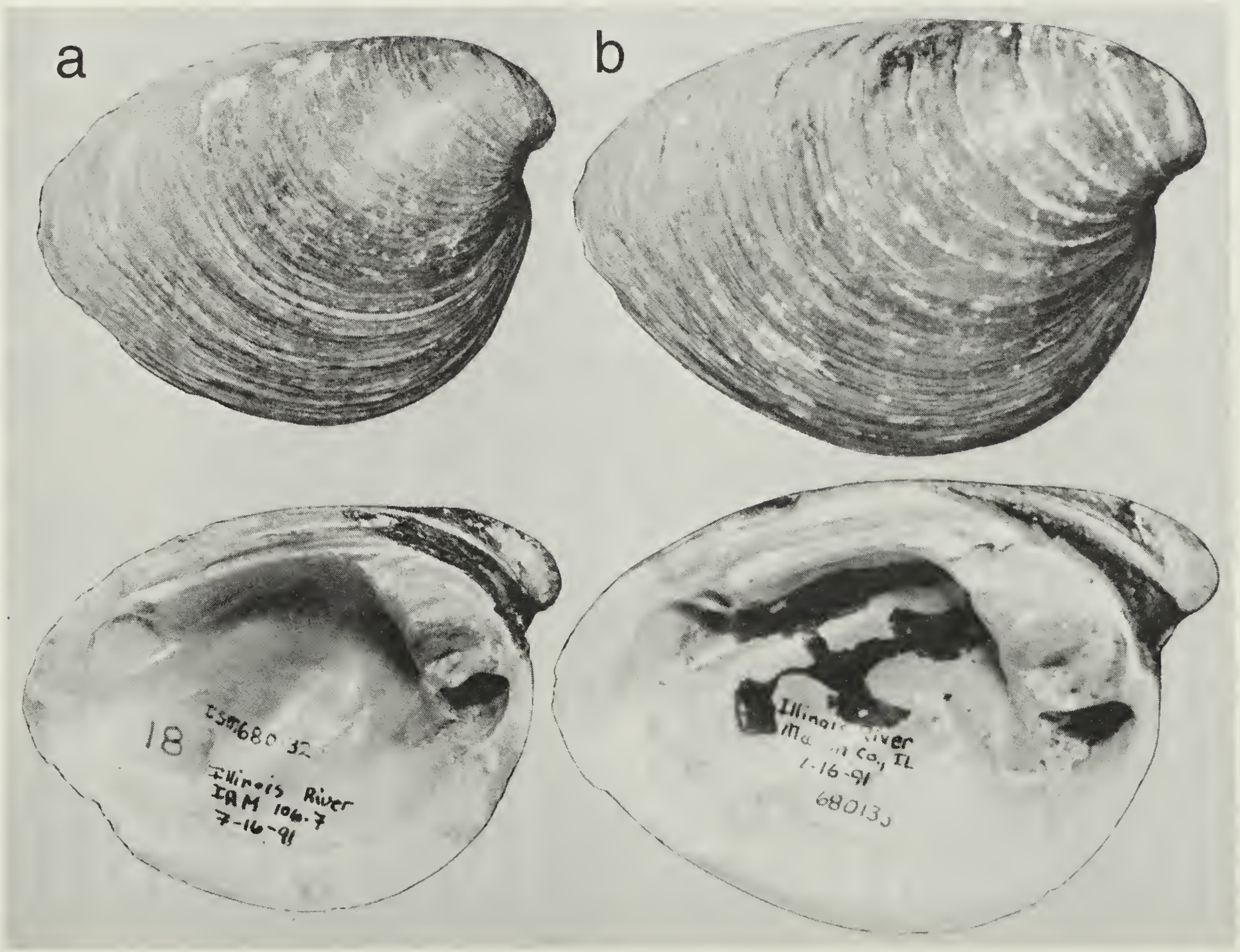
Table 1. Freshwater unionid bivalves from three collection units at the Nancy's Point site (11F2758), Fulton County, Illinois.

Taxon	Unit			Total	Percent
	No. 1	No. 2	No. 3		
Anodontinae					
Arcidens confragosus (Say 1829)	2	0	0	2	0.1
Lasmigona costata (Rafinesque 1820)	2	2	1	5	0.3
Strophitus undulatus (Say 1817)	9	7	5	21	1.3
Ambleminae					
Amblema plicata (Say 1817)	65	56	26	147	9.4
Elliptio crassidens (Lamarck 1819)	12	4	8	24	1.5
Elliptio dilatata (Rafinesque 1820)	316	423	242	981	62.6
Fusconaia ebena (Lea 1831)	7	9	4	20	1.3
Fusconaia flava (Rafinesque 1820)	34	10	7	51	3.3
Megalonaias nervosa (Rafinesque 1820)	5	0	0	5	0.3
Pleurobema coccineum (Conrad 1834)	3	7	0	10	0.6
Pleurobema rubrum (Rafinesque 1820)	7	2	8	17	1.1
Pleurobema spp.	2	3	1	6	0.4
Quadrula nodulata (Rafinesque 1820)	2	0	0	2	0.1
Quadrula pustulosa (Lea 1831)	11	6	3	20	1.3
Quadrula quadrula (Rafinesque 1820)	2	2	0	4	0.3
Quadrula spp.	2	1	4	7	0.4
Tritogonia verrucosa (Rafinesque 1820)	2	2	0	4	0.3
Lampsilinae					
Actinonaias ligamentina (Lamarck 1819)	33	20	10	63	4.0
Ellipsaria lineolata (Rafinesque 1820)	1	1	0	2	0.1
Epioblasma triquetra (Rafinesque 1820)	1	2	0	3	0.2
Lampsilis siliquoidea (Barnes 1823)	0	0	2	2	0.1
cf. *Lampsilis teres* (Rafinesque 1820)	0	1	0	1	0.1
Lampsilis spp.	1	1	2	4	0.3
Leptodea fragilis (Rafinesque 1820)	2	0	0	2	0.1
Ligumia recta (Lamarck 1819)	1	0	0	1	0.1
Obliquaria reflexa Rafinesque 1820	6	6	5	17	1.1
Obovaria olivaria (Rafinesque 1820)	2	0	1	3	0.2
Potamilus alatus (Say 1817)	7	1	2	10	0.6
Toxolasma parvus (Barnes 1823)	6	2	2	10	0.6
Truncilla donaciformis (Lea 1828)	12	19	3	34	2.2
Truncilla truncata Rafinesque 1820	33	35	21	89	5.7
Unionidae spp.	125	70	61	256	–
Total	713	692	418	1823	100.0

Figure 1. *Pleurobema rubrum* from a subfossil shell bed in the Illinois River in Mason County, Illinois. (a) ISM 680132 (Length: 70.6 mm); (b) ISM 680133 (Length: 83.1 mm).



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Sterol Composition and Distribution in Carnivorous Plants, *Sarracenia flava*, *Sarracenia purpurea*, and *Dionaea muscipula*

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ABSTRACT

Lipids extracted from carnivorous plants comprising 2 pitcher plants (*Sarracenia flava* and *purpurea*) and *Dionaea muscipula* and from grasses harvested in the same area, were saponified and the unsaponifiables (UNS) chromatographed to yield the sterols which were surveyed by GC and analyzed by GC/MS. β-Sitosterol was most prominent in the carnivorous plants, especially, in the roots of the *Sarracenia* plants and in *Dionaea* top portions, but stigmasterol ranged far lower and was undetected in several mixtures. As based on the 3 sterols, cholesterol comprised 4.5 and 5.7% of the grass UNS and was comparable to the levels for *S. flava* root and *D. muscipula* leaf products. However, the values ranged higher in UNS (up to 29% cholesterol) for most of the carnivorous plant mixtures screened. Possibly, nonphotosynthetic pathways involving insect prey and bacterial action, appear likely for the carnivorous plants investigated.

INTRODUCTION

The carnivorous plants gain nutrition by photosynthesis as well as by digestion of insect prey which they lure and trap by passive (pitfalls) or active ('steel' trap) modes. Although the absorption of nutrients from animals might have constituted one approach in areas with poor soil characteristics, relative to chemical makeup, it is currently felt that this mechanism may be of lower importance. Furthermore, many questions arise as to the digestion and assimilation of prey nutrients and the need for bacterial involvement in the process (Albert et al., 1992; Juniper et al., 1989). The problems and inconsistencies, notwithstanding, a study of the animal-based sterol, cholesterol, relative to deposition and the distribution in plants with active and passive modes of entrapment may contribute novel concepts in our knowledge of the intermediary metabolism.

Sterols, both free and esterified in *Nepenthes*, were shown to contain β-sitosterol, as the main component; 1% of either mixture comprised cholesterol (Wan et al.,1976). β-

Sitosterol was also prominent in the roots of *S. flava* (Miles and Kokpol, 1976) and in the roots and top portions of *S. purpurea* (Hooper and Chandler, 1984) and stigmasterol has been isolated from the pitchers at variable levels (Palmer et al., 1978; Hooper and Chandler, 1984). As based on the injection of tritiated precursor (5α-lanost-24-ene-3β, 9α-diol) directly into immature *Sarracenia purpurea* pitchers, the label could not be detected 10 days later in stigmasterol, indicative of a limited synthesis by the young plant (Palmer et al, 1978). Among other unsaponifiables (UNS), aliphatic hydrocarbon mixtures displaying wide variations in components have been reported for two *Drosera* species and *S. psittacina* (Sever et al., 1972; Miles et al., 1975) and compared with the ranges in fatty acids by the last group. The carnivorous plants present complex mixtures of carotenes, terpenes and other phytochemicals as reviewed by Juniper et al. (1989).

The current study was undertaken to determine the presence of cholesterol in UNS derived from *Dionaea muscipula* and the two pitcher plants, *S. flava* and *S. purpurea* and its relative distribution among the phytosterols. A sample of grasses harvested in the same area was included as a control. A preliminary report on the plant lipids has been presented earlier (Gershbein and Brown, 1991).

MATERIALS AND METHODS

Redistilled AR solvents were employed throughout and all glassware was degreased with 2:1 chloroform-methanol (v/v) and ethyl ether, the respective lipid - extracting media. Filtrates, after drying over anhydrous sodium sulfate, were concentrated under vacuum, the last portion of solvent being removed under nitrogen. All lipid samples were stored at 25°C under nitrogen. Sigma Chemical Co., St. Louis, MO was the source of the acetate standards.

Mature plants collected during August in the city limits of Wilmington, NC and comprising *Dionaea muscipula, Sarracenia flava, Sarracenia purpurea* and grasses indigenous to the area, were forwarded to the laboratory. The 'grasses' comprised a mixture of *Fimbristylis autumnalis* and *Panicum scoparium* in addition to broom sedge (*Andropogon virginicus*), bunch grass (*Muhlenbergia capillaris*), sweet bay (*Magnolia virginiana*), red bay (*Persea boronis*), bitter gallberry (*Ilex glabra*) and dog tongue (*Trilisa odoratissima*).The plants were cleaned of all debris, washed copiously with 0.90% NaCl and separated according to root, rhizome, leaf and tuber. The plant material was macerated and the lipid extracted with ethyl ether in a blender and after 72 h at 25°C, the contents were filtered and the residue extracted with ethyl ether. The filtrates were concentrated, and the residue taken up in ethyl ether, washed with several portions of water and dried. Removal of solvent yielded the lipids. A portion of the plant material from several batches was also submitted to Soxhlet extraction with chloroform-methanol and the lipids processed separately.

The lipids were saponified by refluxing with 20% NaOH in 95% ethanol (1.5 ml/g lipids) for 17 h, after which the mixture was cooled, diluted with water and extracted portionwise with ethyl ether. The ethereal layer was washed with water, the filtrate dried and concentrated, yielding the UNS. (The fatty acids or saponifiables in the initial alkaline solution, were processed following acidification, extraction of the acids with ether, washing with water portions and concentration of the dried filtrate).

UNS as a 1% solution in petroleum ether (b. 30-60°C) was fractionated over alumina (Alcoa F-20; 40 g/g UNS) and the column eluted with petroleum ether as such and containing 5% and 10% chloroform, 100% chloroform and finally 100% methanol. Each solvent was used at 25-30% of the initial volume. Fractions I-V resulted on removal of the respective fluids. Hydrocarbons occurred in Fractions I, II and III and the alcohols and sterols, in Fraction V. Some ketonic matter was present in Fraction III. Fraction V was acetylated by refluxing with acetic anhydride and pyridine for 45 min, cooled and n-hexane added. This solution was washed with portions of 5% HCl then water, until the aqueous layer was neutral. Drying of the hexane solution and concentration of the filtrate followed. The extraction of lipids and the fractionation procedures have been applied by this laboratory to mammalian samples with success (O'Neill and Gershbein, 1976; Gershbein et al., 1980).

GC and GC/MS Analysis

A Shimadzu GC-6AM instrument with DB-1 wide bore capillary column using an flame ionization detector was applied to the preliminary survey of components. The injector temperature was set at 250°C and that of the column was started at 130°C and maintained for 60 s and then increased to 280°C at the rate of 5°C/min.

For GC/MS, a Hewlett Packard 5890 gas chromatograph operated in the splitless mode was interfaced to a Hewlett Packard Mass Selective Detector. GC conditions: 90°C for 0 min, 5°C/min to 330°C; capillary column: J&W DB-5MS, 30 m, 0.25 mm i.d., 0.1 μm film thickness. The instrument was operated in the selected ion monitoring mode. Initially, ions with m/z = 179 were passed through the mass selective detector to detect the internal standard, phenanthrene. At 25 min into the run (after elution of the phenanthrene), the mass spectrometer was reset to monitor ions at m/z = 255 (common to the steroid derivatives studied), 368 (M^+- acetic acid for cholesteryl acetate), 394 (M^+- acetic acid for stigmasteryl acetate) and 396 (M^+- acetic acid for β-sitosteryl acetate) in order to detect important fragment ions from the extracted plant sterols. The instrument was set for low resolution and maximum sensitivity.

Samples initially screened by GC as such were combined with 0.5 ml of internal standard solution (916 μg/ml in heptane) and then diluted with this solvent to fill the autosampler vial to about 1.5 ml. The samples and appropriate standards were analyzed by GC/MS. The resulting peak areas (from mass spectrograms based on m/z values of 368, 394 and 396) were divided by the corresponding internal standard peak areas. The peak ratios from the standards were fit to a least squares line (non-zero intercept) which was used to calculate the amount of each analyte in the samples. Squalene in the hydrocarbon fractions was analyzed by GC (O'Neill and Gershbein, 1961).

RESULTS

Total lipids extracted from the cleaned plants employing solvent at 25°C or Soxhlet extraction and the distribution of saponifiables (fatty acids) and UNS on saponification are presented in Table 1. The percentages for the lipids and UNS are cumulative and include all respective plant portions as the leaf or pitcher, tuber, rhizome and root. Of the products obtained by chromatography over alumina, Fractions I, II and III, occurred in low

or trace amounts, the main one comprising alcohols + sterols (Fraction V) but with UNS recovery being lowest with *Dionaea muscipula*.

Hydrocarbons which occurred in Fractions I-III, ranged high in the sterol precursor, squalene. Saturated homologs were prominent in Fraction I, as illustrated for *S. flava* (Fig. 1). Chromatograms for Fraction V acetates derived from the plant samples and in which the peaks for cholesterol, stigmasterol and β-sitosterol are pinpointed, are shown in Fig. 2. Mammalian steroids as testosterone acetate could not be detected among the peaks of Fractions V.

DISCUSSION

It will be noted (Table 1) that the total lipids extracted from the carnivorous plants and grass mixture, from the same vicinity, occurred at 0.7-1.8% and of which UNS made up 7-10% of the lipids except for a higher level in *S. purpurea*. With the exception of a lower recovery for *D. muscipula*, UNS of the plant types consisted of 72-85% alcohols and sterols as based on column chromatography; the C-nos. ranged from C_{12} to C_{47} with more peaks in the grass mixture. The hydrocarbon-containing fractions eluted earlier with petroleum ether media, were high in squalene and displayed C-nos. of up to C_{46} (carnivorous plants) and to C_{38} (grasses). Considering the complexity of mixtures and of compounds reported for carnivorous plant types, the occurrence of many components in Fraction IV, and certainly, of those in Fraction V, would be expected. However, an exhaustive analysis of such agents is deferred presently, attention being directed to the sterols with emphasis on cholesterol.

In the evaluation of cholesterol levels in the various plant specimens (Table 2), sections of plants were sampled and the individual UNS isolated and chromatographed. Stigmasterol was quite low in the pitcher series as to be undetected in two of the *S. purpurea* root and pitcher in addition to the tuber of *D. muscipula*. β-Sitosterol ranged higher in the rhizome and roots of the *Sarracenia* plants as well as in *D. muscipula* top portions. Cholesterol occurred in each of the samples, including the grasses (0.67 and 0.79 mg/g UNS). Based on its percentage in the mixture with the two phytosterols, the cholesterol levels were low (4.0 and 5.7%) in grasses as *S. flava* root (4.5%) and *D. muscipula* leaf (4.2%), but definitely higher in the remaining six carnivorous plant samples (11-29%).

It should be pointed out that in the mixture with stigmasterol and β-sitosterol, the grasses presented a higher cholesterol level as compared to the findings of Wan et al. (1972), who deduced a value of 1% of the total from *Nepenthes*. Currently, a problem in the absorption of stigmasterol as mentioned in relation to tritiated precursors (Palmer *et al.*, 1978), is reflected in the findings. One would surmise that an elevation in cholesterol level in contrast to the grasses might indicate importance of the prey utilized by the carnivorous plants. The prominent prey of plants such as *S. flava* is diptera and such arthropods would contribute to cholesterol in Fraction V of the UNS portion. At least, the current pilot indicates that as based on cholesterol, the use of the carnivorous plants as harvested in late August in this American locale, may lead to a tool in following intermediary metabolism of this sterol. A possibility also exists that aside from prey,

cholesterol might arise from endogenous *de novo* biosynthesis so that labeling studies are definitely in order.

ACKNOWLEDGMENT

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Table 1. Total lipids of plant samples and pertinent fractions.

Sample, Mode of Extraction	*S. flava*, 25°C	*S. purpurea*, 25°C	*D. muscipula*, Soxhlet	Grasses, 25°C	Grasses, Soxhlet
Wt. cleaned plant, g	101.5	55.6	58.1	93.5	147.7
Wt. lipids, g	1.83	0.80	0.41	1.34	1.61
Lipids, %	1.82	1.44	0.71	1.43	1.09
Wt. saponifiables, mg (fatty acids)	238	150	76	435	93
Wt. UNS, mg	163	130	31	140	38
Wt. UNS, mg chromatographed over alumina	153	113	25	74	25
Fraction recovery, %					
I	Tr	2.7	Tr	4.0	Tr
II	Tr	0.9	Tr	Tr	Tr
III	Tr	Tr	Tr	Tr	Tr
IV	2.0	1.8	4.0	10.8	8.0
V	85.0	84.1	56.0	75.7	72.0

Tr, trace.

Table 2. Analysis of cholesterol and phytosterols in plant UNS as based on GC/MS of Fraction V Acetates.

	Cholesterol	Stigmasterol mg/g UNS	β-Sitosterol	Cholesterol in mixture, %
Sarracenia flava				
Rhizome	4.9	0.30	11.5	29.3
Root	2.2	2.2	44.4	4.5
Leaf	1.2	0.70	9.2	10.8
Sarracenia purpurea				
Rhizome	4.8	1.9	47.6	8.8
Root	5.0	ND	40.0	11.1
Leaf	1.9	ND	6.3	23.2
Dionaea muscipula				
Tuber (Soxhlet)	1.0	ND	3.3	23.3
Leaf (Soxhlet)	2.2	5.6	44.4	4.2
Grass Mixture				
Leaf	0.67	2.7	13.3	4.0
Leaf (Soxhlet)	0.79	5.3	7.9	5.7

Unless otherwise stated, the initial lipids were extracted at 25°C.
ND, not detected.

Figure 1. Chromatogram of Fraction I from plant UNS of *S. flava* chromatographed over alumina. A, Tricosane; B, Pentacosane; C, Squalene.

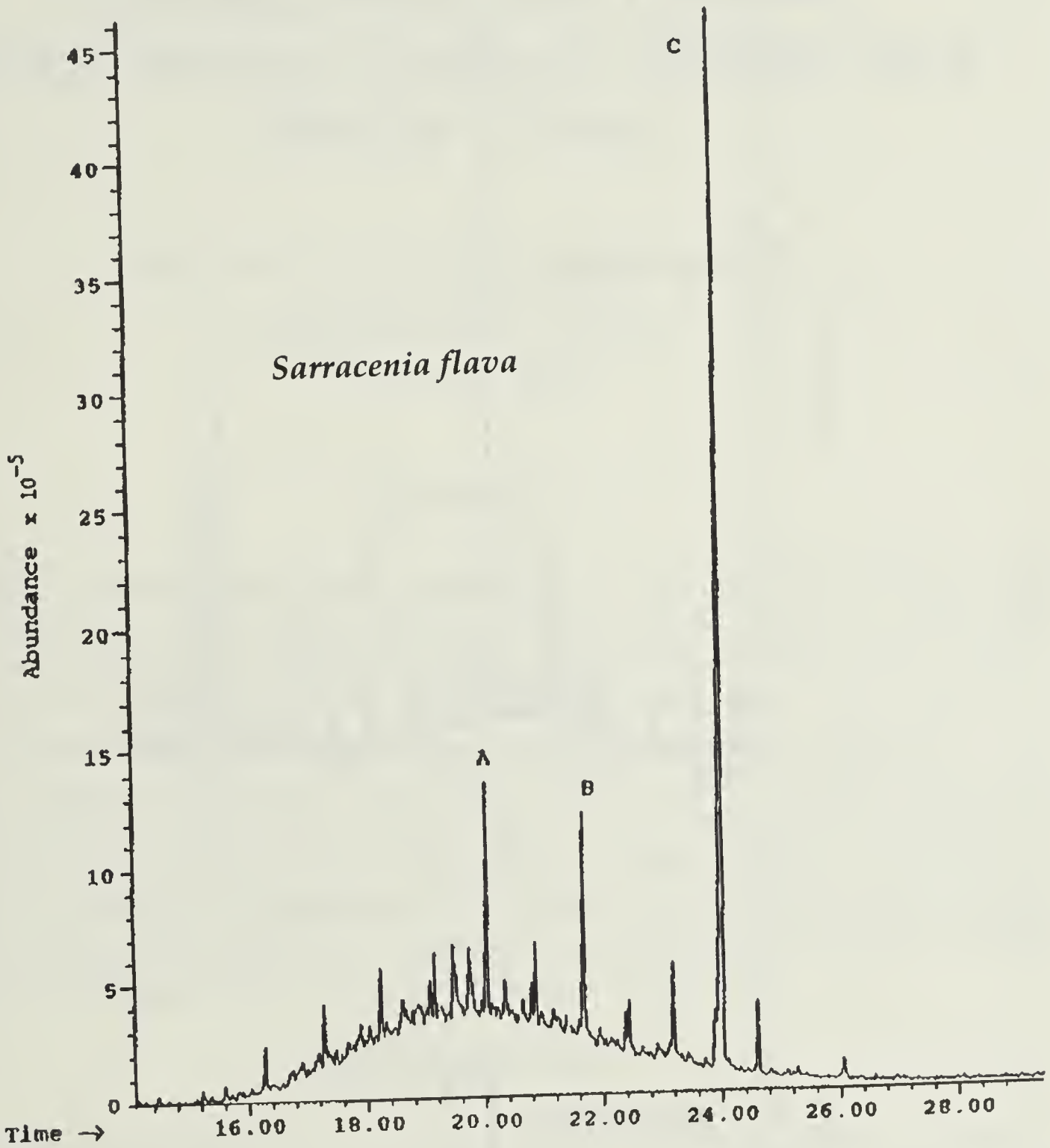
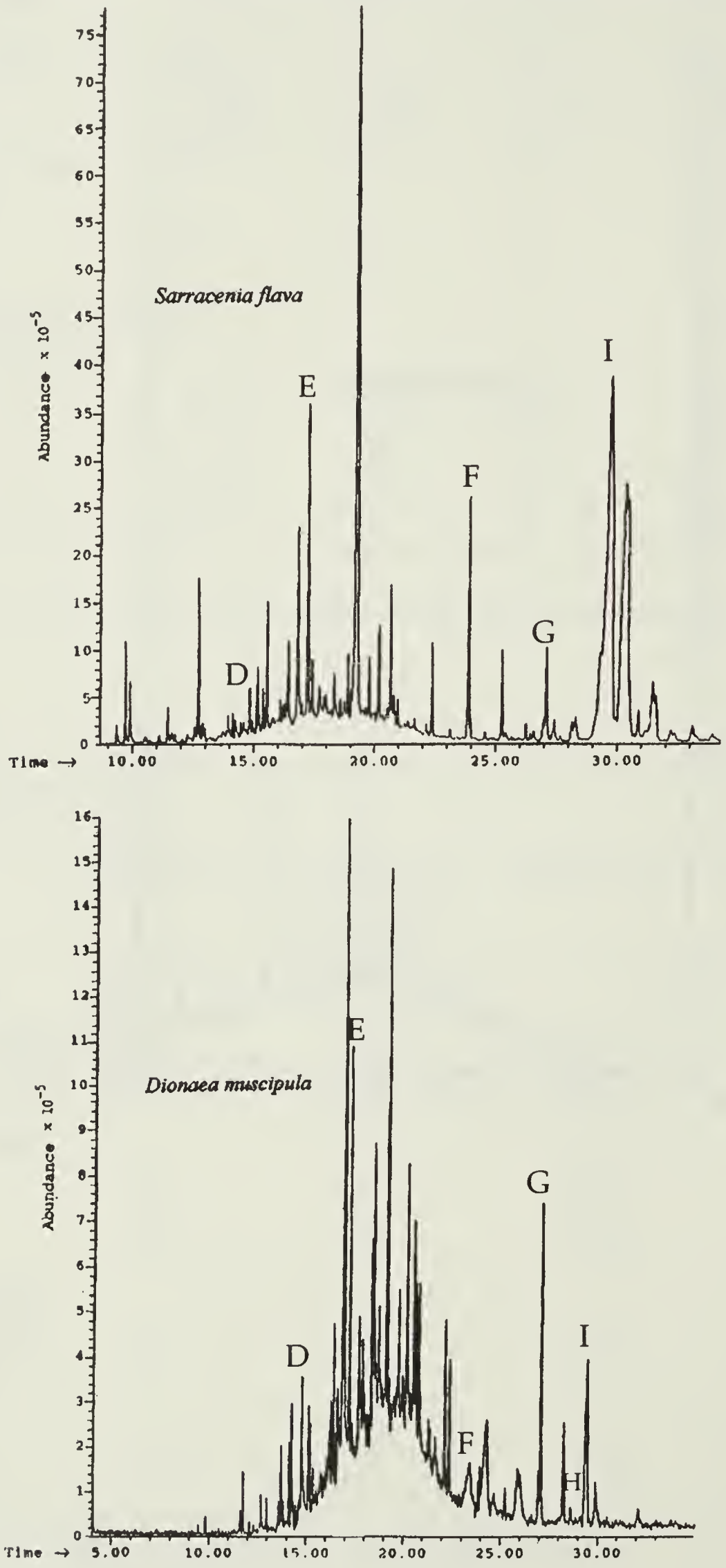


Figure 2. Tracings of plant alcohols + sterols (Fraction V from UNS chromatography over alumina). Acetates of D, 5-Tetradecen-1-ol; E, 1-Hexadecanol; F, 1-Docosanol; G, Cholesterol; H, Stigmasterol; I, β-Sitosterol.



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Systematic Studies of the Retention of Organic Compounds on an Octadecylsiloxane Column Using Sodium Dodecyl Sulfate as a Mobile Phase

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ABSTRACT

The retention of ionizable, polar and nonpolar solutes on an octadecylsiloxane column (ODS) when sodium dodecyl sulfate (SDS) is used as a mobile phase was investigated. Studies were conducted at different surfactant concentrations, mobile phase acidities, concentrations of 2-propanol and ionic strengths of the mobile phase. The elution time of the ionizable solutes, aniline, pyridine and benzoic acid, is dependent on the electrostatic interaction (repulsion or attraction) with the negatively charged sites of the surfactant molecules bonded to the stationary phase. The micellar system resembles the reverse-phase chromatographic system in the retention of polar compounds (nitrobenzene, acetophenone, phenol, and benzaldehyde) and nonpolar compounds (toluene and benzene). The retention time of these solutes is determined by their partition between the nonpolar portions of the stationary phase and the lipophilic core of the micelle.

INTRODUCTION

At surfactant concentrations above the critical micellar concentration (CMC), micelles are formed in the aqueous solution, i.e., aggregation of surfactant molecules. Therefore, the aqueous solution consists of two phases, the micelle and the bulk water. These, together with the stationary phase, form a three-phase system. Armstrong and Nome (1981) demonstrated the use of micellar surfactants, at concentrations above the critical micellar concentration, as mobile phase components in liquid chromatography. They proposed a model for the partition of the solute between the stationary phase and the aqueous phase (Figure 1). Accordingly, the solute is distributed between the micelle and the bulk water, the bulk water and the stationary phase, and the stationary phase and the micelle. The elution behavior of the solute is based on the combined effects of the three partition coefficients.

Since the introduction of micellar chromatography, other investigations have been reported on the use of surfactants as a mobile phase. Yarmchuk and co-workers (1982) studied the selectivity of methylsiloxane type column when sodium laurylsulfate and

dodecyltrimethylammonium bromide were used as mobile phases. Dorsey and co-workers (1983) enhanced column efficiency with sodium dodecyl sulfate as a mobile phase by the use of up to 3% n-propanol and temperatures of about 40°C. Landy and Dorsey (1985) extended the previous study to include the cationic surfactant, cetyltrimethylammonium bromide (CTAB), and the nonpolar surfactant, Brij-35. Arunyanart and Cline Love (1985) examined the retention behavior of the cyano type stationary phase when SDS was used as a mobile phase. Berthod and co-workers (1986) compared retention behavior of silica gel, C_1, C_8, C_{18}, and CN bonded stationary phases at room temperature and pH 6.0. Their work was extended to the additive effects of 0.l0 M NaCl and 5% methanol on the adsorption of SDS and CTAB (1986). Berthod and Roussel (1988) studied the effect of several organic modifiers (methanol, propanol, pentanol and tetrahydrofuran) on column efficiency. Kord and Khaledi (1992) used amino acids to compare elution strength and selectivity between micellar liquid chromatography and ion pair chromatography. Rodgers and Khaledi (1994) extended the above work with amino acids to include the effect of the acidity of the mobile phase.

Previously reported investigations have not provided a comprehensive examination of the retention behavior of organic compounds ranging from polar to ionizable to nonpolar on the octadecylsiloxane column when sodium dodecyl sulfate is used as a mobile phase. This work provides a study of this type.

MATERIALS AND METHODS

Instrumentation

The HPLC system consisted of a Perkin Elmer Series 3 Liquid Chromatograph equipped with a variable wavelength LC-65T UV detector/oven, an LC1-100 integrator and a 20 µL Rheodyne sample injector (Model 7125, Berkeley, CA). The column (25 cm long and 4.6 mm i.d.) was packed with 5 µm Supelcosil LC-18 (Supelco, In., Bellefonte, PA). The void volume of the system was calculated by using the peak of injected water. All pH measurements were performed with ALTEX Model 3560 Digital pH meter and Corning combination glass electrode. The flow rate was fixed at 1.0 mL min^{-1}, the wavelength was set to 254 nm and the column temperature was maintained at 40°C.

Chemicals and Reagents

Sodium dodecyl sulfate, benzene, toluene, pyridine, aniline, benzoic acid, benzaldehyde, acetophenone and nitrobenzene were obtained from Aldrich Chemical Company, Inc. These chemicals were used as received. The stock solution of 0.15 M SDS was prepared in deionized water and filtered through a 0.45-µm membrane (Rainin Instrument Co., Inc., Woburn, MA). The mobile phase was adjusted to the desired pH with 0.01 M Na_2HPO_4/H_3PO_4. Stock solutions of the test solutes were prepared in 0.10 M SDS solution. The working concentrations were as follows: benzene (1198 µg/mL), toluene (1254 µg/mL), pyridine (100 µg/mL), aniline (100 µg/mL), benzoic acid (100 µg/mL), benzaldehyde (5 µg/mL), acetophenone (5 µg/mL), phenol (100 µg/mL) and nitrobenzene (100 µg/mL).

Column Preparation and Reliability

The ODS-bonded silica column was coated with SDS by passing an aqueous solution of 0.10 M SDS at a flow rate of 1.0 mL min^{-1} through the column for 2 h. Following

multiple separations the column was regenerated by washing with deionized water for 10 min at 1 mL min^{-1}, followed by pure methanol until all surfactant was removed (about 1 h), and then with deionized water until all methanol was removed (about 1 h).

The reliability of the method was tested by injecting quadruplicate samples. A relative standard deviation of less than 0.5% was found. Based on these results, all studies were performed using single injections.

The capacity factor (k´) was calculated using:

$$k' = \frac{t_r - t_o}{t_o}$$

where: t_r = total retention time of the solute
t_o = retention time of the solute in mobile phase

RESULTS AND DISCUSSION

Effect of Surfactant Concentration

The behavior of each solute was studied at concentrations of SDS ranging from 0.05 M to 0.15 M. As the concentration of SDS increased, the capacity factor decreased for all solutes (Figure 2). This is due to an increase in the number of micelles in the mobile phase as the concentration of surfactant increases (Yarmchuk, et. al., 1982).

These results are in contrast to reverse-phase ion-pair chromatography where the concentration of ionic surfactant is below the CMC. Under those conditions, while an increase in the concentration of surfactant has no influence on the retention of polar and nonpolar solutes, the retention of those compounds which are attracted electrostatically to the surfactant is increased (Snyder and Kirkland, 1979).

When surfactant is above the CMC, polar and nonpolar solutes are partitioned between the polar bulk aqueous phase and the nonpolar portions of the micelle and the stationary phase (Figure 1). The capacity factors for the polar and nonpolar compounds studied decrease in the same order as their polarity increases (Figure 2). This indicates that for these types of compounds the micellar system resembles reverse-phase chromatography.

The results in Figure 2 show a sharper decrease in the retention of the ionizable solutes, aniline and pyridine, as compared to the polar and nonpolar solutes. This can be explained by assuming that such ionizable solutes can interact electrostatically as well as hydrophobically with the micelle and the stationary phase.

Micelle Bulk pH Effect

When the pH was varied from 2.82 to 7.00, the capacity factor of the nonpolar and polar solutes was found to be independent of the acidity of the mobile phase (Figure 3). On the other hand, the capacity factor of ionizable benzoic acid decreased as the pH of the mobile phase increased. The pk_a of benzoic acid (4.21) indicates that the concentration of the benzoate anion increases as the pH of the solution increases. Consequently, electrostatic

repulsion between the benzoate anion and the surfactant-modified stationary phase may increase its concentration in the mobile phase and therefore decrease its elution time.

The capacity factors of the ionizable species, aniline and pyridine, increased as the pH of the mobile phase decreased. From the pk_a values of the anilinium cation (4.60) and the pyridinium cation (5.22), the two solutes are expected to be partially ionic in solutions at pH below their pk_a values. This implies that the increase in capacity factor at the lower pH values may be due to the net electrostatic interaction of the solute with the micelles and the stationary phase.

The asymmetry factors calculated for all solutes except pyridine were less than 1.3. It is interesting to note that at pH 2.91 the pyridine peak showed extreme tailing (asymmetry factor = 9.8) which improved as the pH increased to 6.97 (asymmetry factor = 4.3). After washing the surfactant off the column with 300 mL of pure methanol and using methanol-water as a mobile phase, tailing was still observed at the higher pH values and again observed when a new column (never treated with surfactant) was used. These results may be explained by the electrostatic interaction of the pyridinium ion with the unprotonated hydroxyl group of the silica gel particles (Hux and Cantwell, 1984).

Effect of 2-Propanol

In reverse-phase chromatography, it is generally accepted that the addition of an organic modifier to the mobile phase decreases its polarity. This, in turn, causes the solvent strength to increase which ultimately leads to shorter retention of solutes. Similar results were observed in this study when the percentage of 2-propanol was increased from 3% to 15% in the presence of 0.10 M SDS in the mobile phase (Figure 4). In addition, there was a greater decrease in the retention of aniline and pyridine than in the other solutes studied. The retention of aniline and pyridine decreased by factors of 0.45 and 0.51, respectively, while the other solutes decreased by an average factor of 0.65 $\pm$ 0.04. The small decrease in capacity factor of the nonionic solutes may be related to the decrease in polarity of the mobile phase as the concentration of 2-propanol increases. The more significant decrease in capacity factors of aniline and pyridine may be a result of a decrease in the number of surfactant molecules bonded to the stationary phase when the polarity of the mobile phase is decreased as the amount of 2-propanol is increased. This decrease in the number of active sites for electrostatic interaction shifts the partition equilibrium of the solute to the mobile phase direction.

Salt Effect

In general, the solubility of an organic solute, in the ionic form, depends on the interaction of both its ionic and its non-ionic portions with the stationary phase. Thus, the retention behavior of such solutes as a function of salt concentration results from a combination of electrostatic and hydrophobic effects. The net effect of increasing the sodium chloride concentration up to 0.10 M was found to affect the slopes of aniline and pyridine more than that of the polar and nonpolar solutes (Figure 5). This may be attributed to the competition between the solute cations and the sodium ion for the active sites on the stationary phase.

SUMMARY

Micellar chromatography can offer several mechanisms for manipulating retention times and controlling column selectivity. The effects of sodium dodecyl sulfate concentration, acidity of the mobile phase, percentage of 2-propanol and concentration of sodium chloride affected the retention times of the weak organic bases (aniline & pyridine) to a greater extent than the weak organic acid (benzoic acid) and the polar and nonpolar solutes studied.

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Figure 1. Diagram illustrating the partition of the solute between the stationary phase, micelle and the bulk aqueous phase.

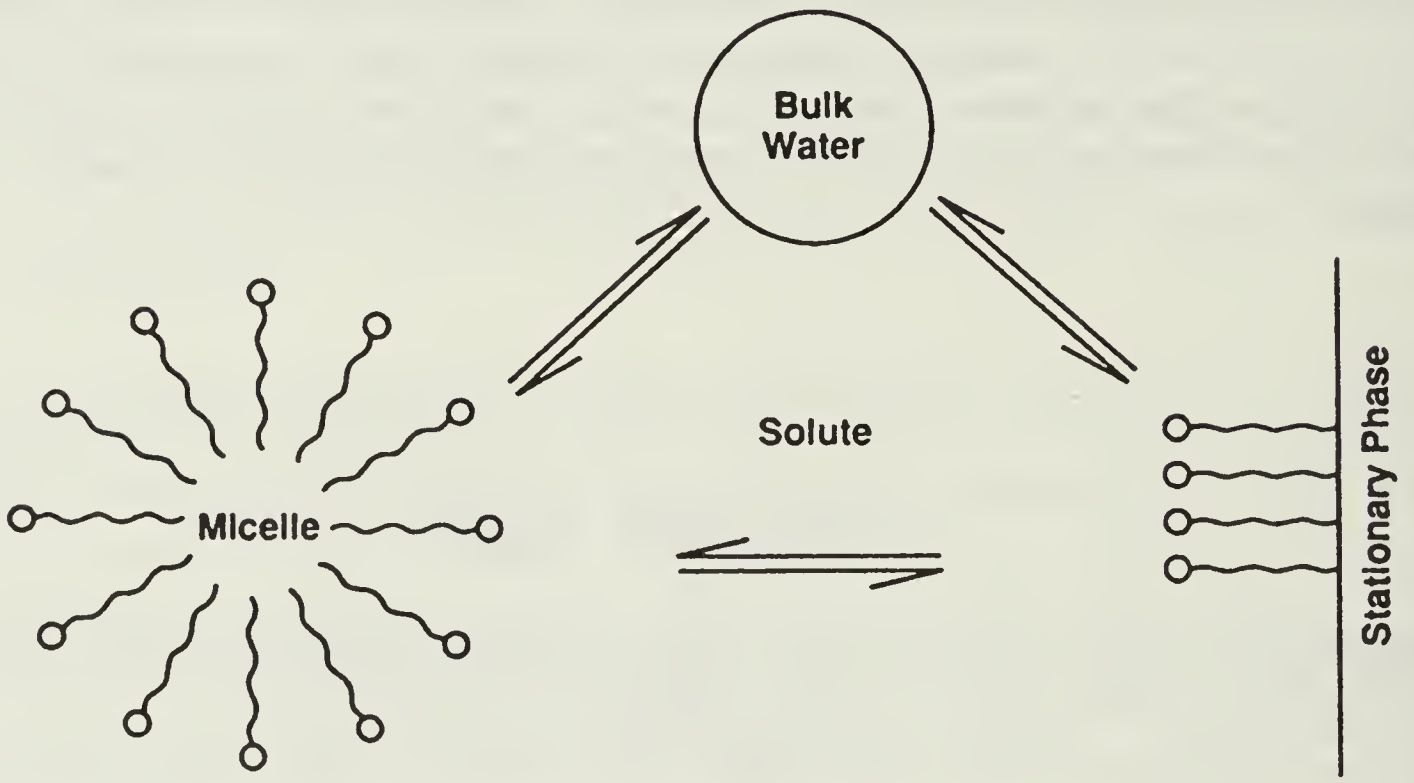


Figure 2. Effect of surfactant concentration on capacity factor. Conditions: eluent pH 3.10, flow rate 1.0 mL/min and 2-propanol (3%). Line identities: (▼) = aniline, (●) = toluene, (□) = pyridine, (O) = benzene, (◇) = nitrobenzene, (Δ) = acetophenone, (▽) = benzoic acid, (▲) = benzaldehyde, (■) = phenol.

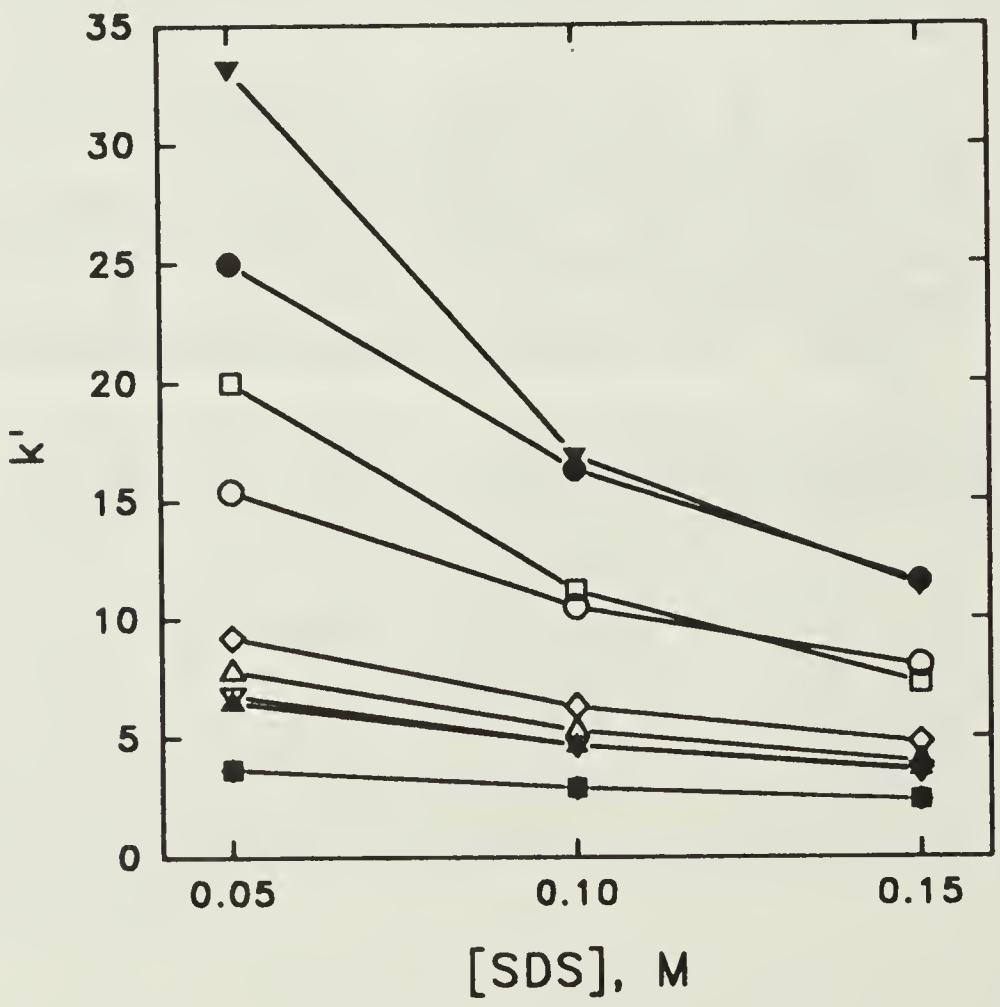


Figure 3. Effect of pH of the mobile phase on the capacity factor. Conditions: 0.10 M SDS concentration, flow rate 1.0 mL/min and 2-propanol (3%). Line identities: (●) = toluene, (▼) = aniline, (O) = benzene, (□) = pyridine, (◇) = nitrobenzene, (Δ) = acetophenone, (▲) = benzaldehyde, (▽) = benzoic acid, (■) = phenol.

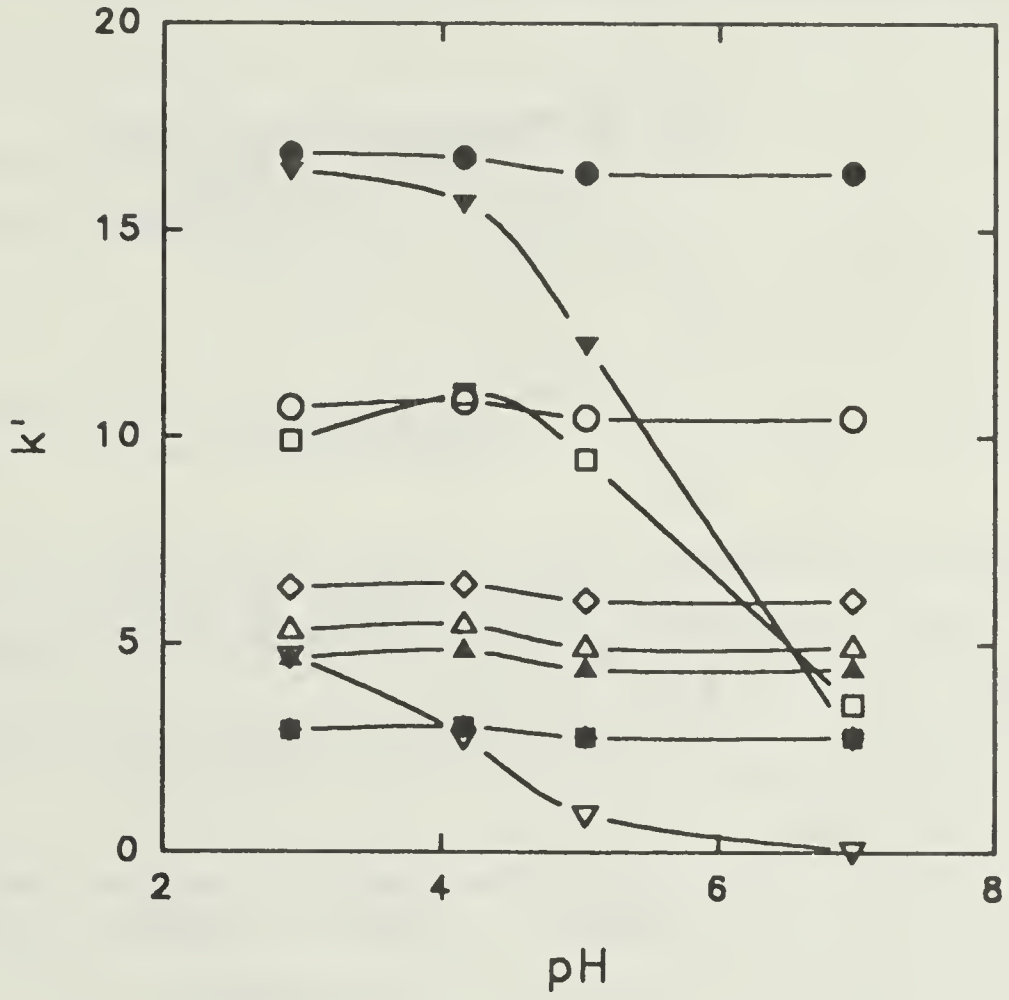


Figure 4. Effect of percentage of 2-propanol on capacity factor. Conditions: 0.10 M SDS concentration, pH 3.06, flow rate 1.0 mL/min. Line identities: (●) = toluene, (▼) = aniline, (O) = benzene, (□) = pyridine, (◇) = nitrobenzene, (Δ) = acetophenone, (▲) = benzaldehyde, (▽) = benzoic acid, (■) = phenol.

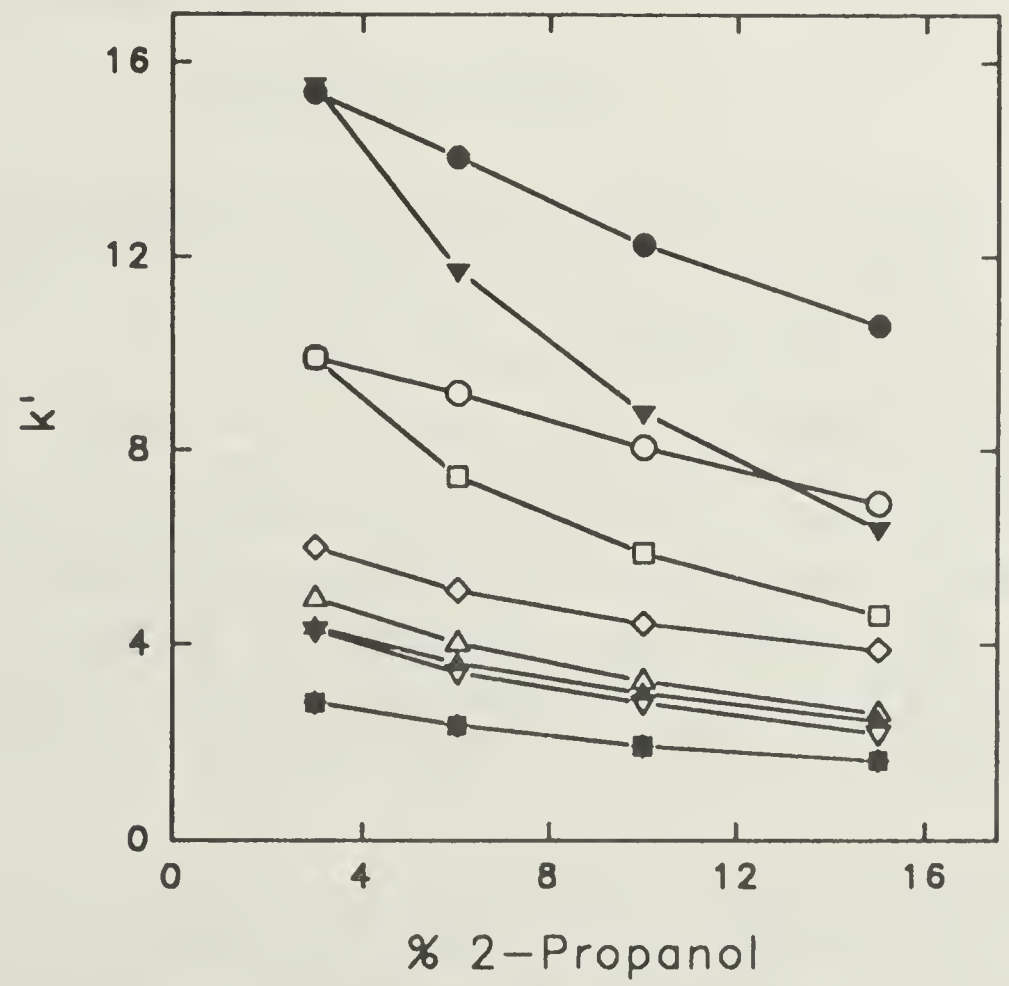
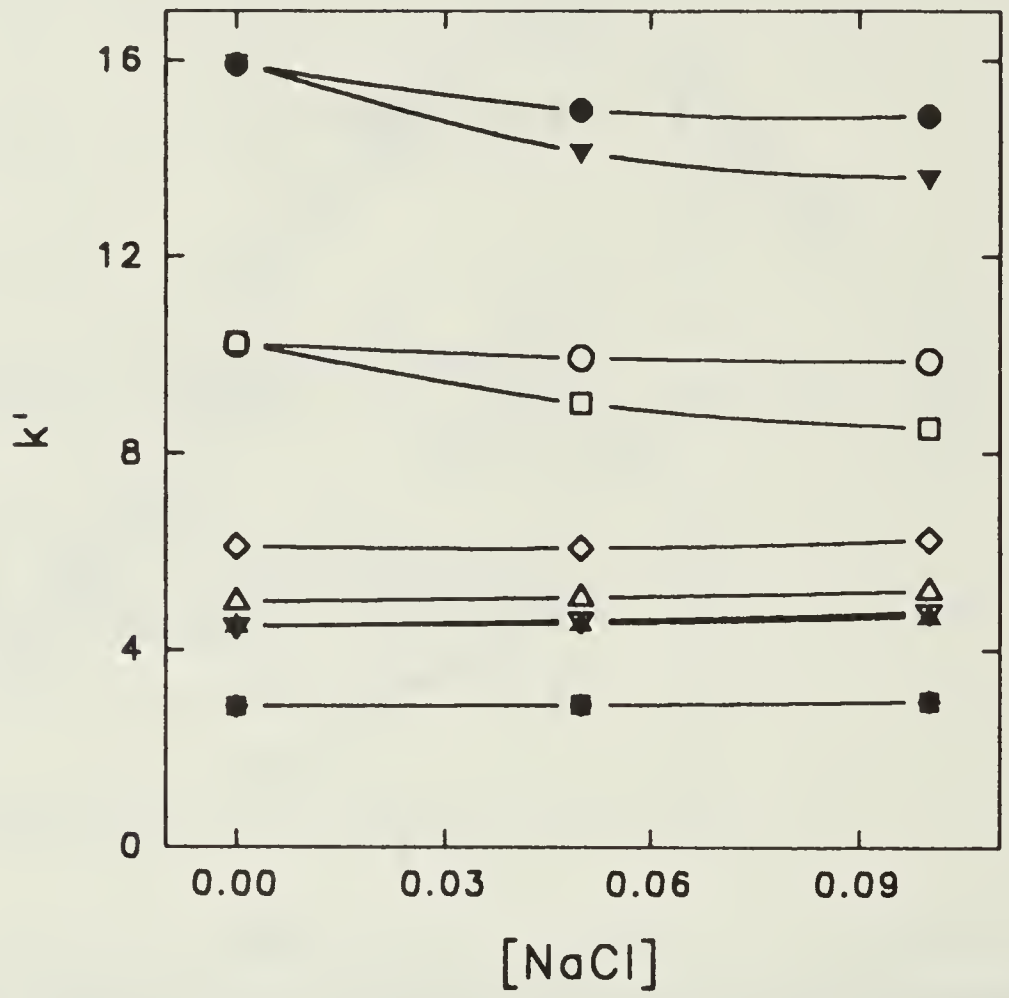


Figure 5. Effect of concentration of sodium chloride on capacity factor. Conditions: 0.10 M SDS concentration, pH 3.10, flow rate 1.0 mL/min and 2-propanol (3%). Line identities: (●) = toluene, (▼) = aniline, (O) = benzene, (□) = pyridine, (◇) = nitrobenzene, (Δ) = acetophenone, (▲) = benzaldehyde, (▽) = benzoic acid, (■) = phenol.



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Variability in Illinois Summer Precipitation: An Analysis of Nine Selected Stations

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ABSTRACT

Summer precipitation totals from nine weather stations distributed across Illinois were examined for the period 1948-1993 to determine recent temporal and spatial variability characteristics. Two descriptors of temporal variability, the coefficient of variation and the frequency that stations experienced summer precipitation totals outside one standard deviation (either high or low), increased since 1970 at eight of the nine stations. The two northern Illinois stations exhibited the greatest increases in variability during the later period. When considering summer precipitation totals from all nine stations, 50 percent of all extreme summer precipitation totals (a station experiencing one of its five wettest or driest summers) were found to have occurred since 1980. The long-term change in the temporal variability of summer precipitation that occurred in the 1970s appears to be related to changes in the global ocean/climate system. Spatial variability in Illinois' summer precipitation amounts, which appears to be related to Illinois' large latitudinal extent and the convective nature of summer precipitation, indicated that a statewide average often produces erroneous results.

INTRODUCTION

Based on precipitation data averaged across Illinois, the summer (June, July, and August) of 1988 was extremely dry, while during the summer of 1993 record amounts of rain fell (NCDC, 1994). However, not all weather stations in Illinois reported record events in either 1988 or 1993. A report by Changnon and Huff (1980) indicated that there were spatial and temporal differences across Illinois when considering July and August precipitation totals from 1895 to 1975. Huff and Angel (1989) identified that long-term trends associated with large precipitation events increased in the northern half of Illinois, while those in southern Illinois remained the same or have decreased. In another study, Changnon, D. (1994) identified that precipitation values analyzed from individual stations, rather than regional or statewide precipitation averages, provided more useful information when describing spatial and temporal variability in precipitation over a region.

In this study, the questions posed were: 1) Is the variability in summer precipitation, over time, consistent across the state?, 2) What extent of the state experiences a similar summer precipitation extreme?, and 3) What are the potential causes for the observed

variability? The authors examined summer precipitation amounts over a span of 46 (1948-1993) years to determine the temporal and spatial variability characteristics. This short period was chosen so that a cyclone frequency data set, currently being developed, could be examined in an effort to explain the variability in summer precipitation. Results described in this paper are based on the 1948-1993 period and could differ when examining other periods.

DATA AND METHODS

Illinois, with its large latitudinal extent, is divided into nine climatic divisions. A cooperative weather station in each division was carefully selected to encompass the north-to-south climate differences across the state (Figure 1). These stations were identified by Huff and Angel (1989) as having high-quality, digitized, long-term daily precipitation records.

Monthly precipitation totals for the nine stations were acquired from the Illinois State Water Survey Midwestern Climate Information Service (MICIS) database. More than 99% of the monthly data was available for the nine stations. For months when data were missing, values from a nearby weather station in the same climatic division were substituted.

Precipitation values for the summer months of June, July, and August were added for each year. Each station's 46-year summer mean, standard deviation, and coefficient of variation were determined. The period was then divided into two equal 23-year samples and similar descriptive information determined for each.

The five wettest and driest summers at each station were determined to investigate the variations in extremes. The mean and standard deviation were calculated for the five wettest and the five driest summers at each station. These ten extreme years were chosen to examine the variability associated with the extreme summers in the 46-year period. A time series showing the frequency of stations experiencing extremes was developed. Comparisons of extreme summers from the first and second half of the period were completed. Finally, years when more than half of the nine selected stations experienced a singular summer precipitation extreme, either wet or dry, were examined.

RESULTS

Spatial and temporal variability of summer precipitation

The small ranges in mean annual summer precipitation values, standard deviations, and coefficients of variation for the nine selected stations indicate that there is little spatial variability across Illinois (Table 1). Based on the data presented, the group of stations appear to have similar summer precipitation climatologies. Interestingly, Illinois' long-term mean annual precipitation increases from north-to-south and can be explained by large-scale climate controls including: frequency and location of storm tracks, differences in air masses colliding over the state, nearness to the Gulf of Mexico, and latitude. However, because the polar jet stream generally moves north into Canada during the summer, precipitation is predominantly derived from convection within the warm, humid

air mass that exists over Illinois (Trewartha and Horn, 1980). This is reflected by a lack of a long-term mean summer precipitation pattern across Illinois.

The study period was divided into two equal length periods, 1948-1970 and 1971-1993, to determine whether the temporal variability had changed (Table 2). Except at Urbana and Fairfield the differences in mean summer precipitation totals at the nine stations were less than one inch. Six of the nine stations reported an increase in precipitation, with Urbana increasing 2.74 inches, while Fairfield experienced the greatest decline, decreasing 1.12 inches. The changes in the standard deviation and coefficient of variation values indicate that the variability from the earlier to later period changed. At five of the nine stations the differences in the standard deviations were greater than those for the mean, indicating significant changes in the variability. Dixon, Joliet, and Peoria experienced the greatest changes in variability, with coefficient of variation values increasing more than 0.15. Anna, located in southern Illinois, experienced the only decrease in variability. This pattern of increased variability in the north to decreased variability in the south indicated that there can be significant spatial differences in variability across Illinois.

Variability associated with extreme summer precipitation

For each station, years with summer precipitation values outside (plus or minus) one standard deviation were identified and categorized by the two 23-year periods in Table 3. All but Effingham experienced more summers outside one standard deviation during the later period. Dixon and Joliet experienced the greatest increase in number of summers outside one standard deviation, going from three to nine and two to ten, respectively. The overall increase in summer variability was associated with fairly consistent increases in the number of summer precipitation totals above one standard deviation (6 of 9) and below (7 of 9).

The 46 summer precipitation totals were ranked for each station. The mean and standard deviation were calculated for the five wettest (highest in the ranked list) summers and the five driest (lowest) summers. In any year, a wet summer at a station represents one of the five wettest summers in the 46-year period, while a dry summer represents one of the five driest summers (Table 4). Based on the student t-test, the difference in means from the average wettest to the average driest summer was significant at the 1% level for all stations. The difference in the amount of summer precipitation from an average wet to an average dry summer was determined by subtracting the mean driest summer from the mean wettest summer; these figures ranged from 11.54 to 15.04 inches for the nine stations.

The two 23-year periods were analyzed to further investigate whether the variability associated with extreme summers had changed. A sample of 90 extreme summers existed, based on nine stations, each with five wet and five dry summers. Identifying how these 90 extremes were distributed over the 46-year period would indicate variability changes.

Nineteen wet events were reported in the first period, with 26 wet events in the second period. Similarly, 15 dry summers were identified in the first period, while 30 dry summers were identified in the second period. When wet and dry summers are combined, 34 extreme summers occurred in the earlier period, while 56 occurred during the later period (Figure 2). Based on the nine selected stations, on average 1.5 stations per year

experienced an extreme during the earlier period, whereas the average for the later period was 2.4 stations. Clearly, the recent period had more dry and wet summers than the early period. Furthermore, for the last 13 summers (1981-1993) the average annual number of stations experiencing an extreme is 3.5, compared to 1.4 for the earlier 33 summers (1948-1980).

Based on the earlier stated criteria, summers were classified as anomalous when more than half the stations experienced a similar extreme. Anomalous summers with wet extremes were 1958, 1981, and 1993, while the anomalous summers with dry extremes were 1984, 1988, and 1991. Five of six anomalous years have occurred since 1980, indicating that variability has increased during the second half of the study period. Also, these results suggest that it is rare to experience one extreme statewide, because only six years in this sample were considered anomalous and there was no year in which all nine stations experienced a similar extreme.

Some of the recent anomalous extreme precipitation summers had great spatial variation. For example, when averaging data from the nine stations across Illinois, 1988 was considered an extremely dry summer with precipitation values ranging from 3.04 inches at Peoria to 8.83 inches at Anna. However, when comparing these values to the departures from average, not all locations experienced a similar decrease in summer precipitation (Table 5). So while Peoria was 8.44 inches below its summer average rainfall (more than 1.5 standard deviations below), Anna was only 2.6 inches below its summer average (less than one standard deviation below).

Table 6 shows the precipitation distribution for 1993, an anomalous wet summer in Illinois. Spatial variation similar to 1988 existed during the summer of 1993. The values ranged from 23.91 inches at Urbana to 10.41 inches at Fairfield. While Urbana was 11.47 inches above its average summer rainfall (more than two standard deviations above), Fairfield was 0.77 inches under its summer average (less than one standard deviation below).

These tables show there are important spatial differences in summer precipitation amounts across Illinois. These north-to-south variations may be explained by the large latitudinal variation that exists in Illinois and the convective nature of summer precipitation. These variations indicate that averaging summer precipitation values across Illinois will provide erroneous values in some years.

Possible explanations for the observed temporal variability

A number of recent studies have tried to link, through teleconnections, some observed climate pattern to potential causes. A paper by Trenberth (1990) identified that the mean values for three indices, the Southern Oscillation Index, the Pacific/North American Index, and equatorial sea-surface temperatures in the Pacific Ocean, significantly changed in the mid 1970s. A paper by Kerr (1992) explained that the mean state for a composite of 40 environmental variables changed in 1976. These papers, as well as Changnon, D. et al. (1990), indicated that the mean state of climate elements shift not only interannually but also over longer periods such as decades.

To determine whether the teleconnection between processes occurring over the Pacific Ocean and climate patterns experienced in North America is real, one must examine the atmospheric general circulation patterns associated with both. Future research will examine the cyclone frequency characteristics over North America and try to link the results from this paper to processes associated with the Pacific Ocean. The authors expect to identify a change in North American cyclone frequency over the last 20 years in association with the temporal variability identified in this study.

Some climate studies have examined potential global climate change associated with increases in carbon dioxide and other trace gases. Many of these studies have indicated that as surface temperatures increase in the mid-latitudes, the variability in various climate elements such as temperature and precipitation will be greater than in cooler periods (Ausubel, 1991; Changnon and Wendland, 1994). This hypothesis was used as a possible explanation for the 1993 heavy precipitation and flooding in the Midwest (NOAA, 1994). However, there is great uncertainty in the scientific community as to whether the climate has began to change in response to increases in greenhouse gases.

CONCLUSIONS

At nine selected stations across Illinois, summer precipitation totals averaged over a 46-year period from 1948-1993 did not exhibit much spatial variability. However, when that period was broken into two 23-year periods greater variability was identified in extreme summer precipitation totals during the later period from 1971-1993.

Coefficients of variation computed for both periods showed that since 1970 the variability has increased at eight of nine stations. Dixon, Joliet and Peoria in northern Illinois exhibited the greatest increases in variability, while Anna's variability decreased. A temporal analysis of summer precipitation extremes identified that 56 of 90 (62%) extremes occurred in the second half of the period (1971-1993). Furthermore, in the recent 13 years, 1981-1993, 45 of 90 (50%) extremes occurred.

More anomalous (five or more stations experiencing the same extreme) dry or wet extreme summers were experienced in the second period of the sample. Most (five of six) occurred since 1980, and three of the six anomalous years have been recorded since 1987.

As identified in previous research, these temporal changes in the summer precipitation variability over Illinois which occurred during the 1970s could be linked to long-term changes in the global ocean/climate system. Another possible explanation could be related to increases in mean temperature due to increases in carbon dioxide and other trace gases. It has been hypothesized that as surface temperatures warm, climate elements such as temperature and precipitation will become more variable.

When considering years with anomalous summer precipitation extremes, 1988 and 1993, significant spatial differences across Illinois were identified. These spatial differences may be explained by Illinois' large latitudinal extent and the convective nature of summer precipitation. This indicates that using a statewide summer precipitation average may provide an incorrect assessment of the true precipitation pattern across Illinois.

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Table 1. Mean, standard deviation, and coefficient of variation for the nine stations. Stations are listed by location from north-to-south.

Station	Mean	Standard Deviation	Coeff. of Var.
Dixon	12.10	3.93	0.32
Joliet	11.52	4.34	0.38
LaHarpe	12.53	3.97	0.32
Peoria	11.48	4.28	0.37
Urbana	12.44	4.05	0.33
Carlinville	10.95	3.54	0.32
Effingham	11.20	3.48	0.31
Fairfield	11.18	3.62	0.32
Anna	11.43	3.88	0.34

Table 2. Mean, standard deviation, and coefficient of variation for two periods, 1948-1970 and 1971-1993.

	1948-1970			1971-1993		
Station	Mean	St. Dev.	C.O.V.	Mean	St. Dev.	C.O.V.
Dixon	11.99	2.76	0.23	12.20	4.82	0.40
Joliet	11.12	3.12	0.28	11.91	5.25	0.44
LaHarpe	12.83	3.66	0.29	12.22	4.23	0.35
Peoria	11.09	3.10	0.28	11.88	5.17	0.44
Urbana	11.07	3.07	0.28	13.81	4.42	0.32
Carlinville	10.89	3.06	0.28	11.02	3.96	0.36
Effingham	11.06	3.20	0.29	11.34	3.73	0.33
Fairfield	11.74	3.40	0.29	10.62	3.74	0.35
Anna	11.84	4.24	0.36	11.02	3.43	0.31

Table 3. The number of summers in each period that experienced precipitation outside one standard deviation from the 46-year mean.

	1948-1970			1971-1993		
Station	Wet	Dry	Total	Wet	Dry	Total
Dixon	2	1	3	5	4	9
Joliet	2	0	2	5	5	10
LaHarpe	4	2	6	3	4	7
Peoria	2	3	5	4	4	8
Urbana	1	5	6	6	2	8
Carlinville	2	2	4	5	3	8
Effingham	2	4	6	4	2	6
Fairfield	3	3	6	2	5	7
Anna	3	1	4	2	5	7

Table 4. The average and standard deviation of the top five wettest and driest summers at each location.

Station	Wet Mean	Std. Dev.	Dry Mean	Std. Dev.
Dixon	19.68	1.50	5.47	1.39
Joliet	20.62	1.92	5.58	1.28
LaHarpe	20.16	1.57	6.67	0.94
Peoria	20.00	2.48	5.48	1.30
Urbana	20.00	2.09	5.77	0.81
Carlinville	17.81	1.38	5.41	0.68
Effingham	17.06	1.45	5.52	1.39
Fairfield	18.45	2.09	5.77	0.79
Anna	19.94	3.16	6.30	0.45

Table 5. 1988 summer precipitation amounts, departures from average, and number of standard deviations from the mean.

Station	Summer Precipitation	Departures from Average	Number of Standard Deviations from Mean
Dixon	3.55 inches	-8.55 inches	>2σ
Joliet	6.38 inches	-5.14 inches	>1σ
LaHarpe	6.79 inches	-5.74 inches	>1σ
Peoria	3.04 inches	-8.44 inches	>1.5σ
Urbana	5.24 inches	-7.20 inches	>1.5σ
Carlinville	8.13 inches	-2.82 inches	<1σ
Effingham	4.90 inches	-6.30 inches	>1.5σ
Fairfield	6.78 inches	-4.40 inches	>1σ
Anna	8.83 inches	-2.60 inches	<1σ

Table 6. 1993 summer precipitation amounts, departures from average, and number of standard deviations from the mean.

Station	Summer Precipitation	Departures from Average	Number of Standard Deviations from Mean
Dixon	22.10 inches	+10.00 inches	>2σ
Joliet	22.87 inches	+11.35 inches	>2σ
LaHarpe	22.36 inches	+9.83 inches	>2σ
Peoria	23.23 inches	+11.75 inches	>2σ
Urbana	23.91 inches	+11.47 inches	>2σ
Carlinville	17.19 inches	+6.24 inches	>1.5σ
Effingham	16.83 inches	+5.63 inches	>1.5σ
Fairfield	10.41 inches	-0.77 inches	<1σ
Anna	11.13 inches	-0.30 inches	<1σ

Figure 1. Location of nine long-term weather stations used in the study. The regions outlined are climate divisions.

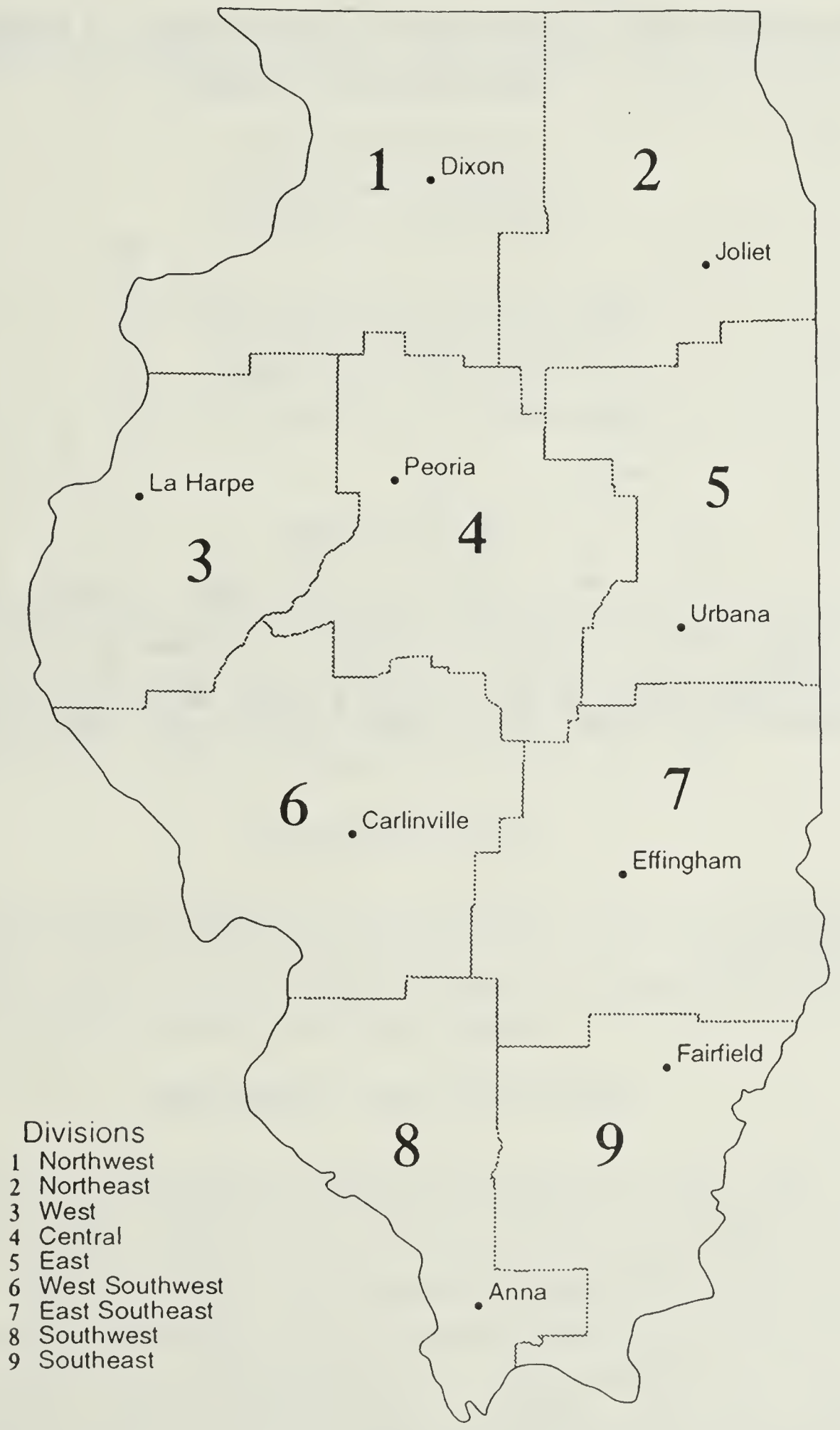
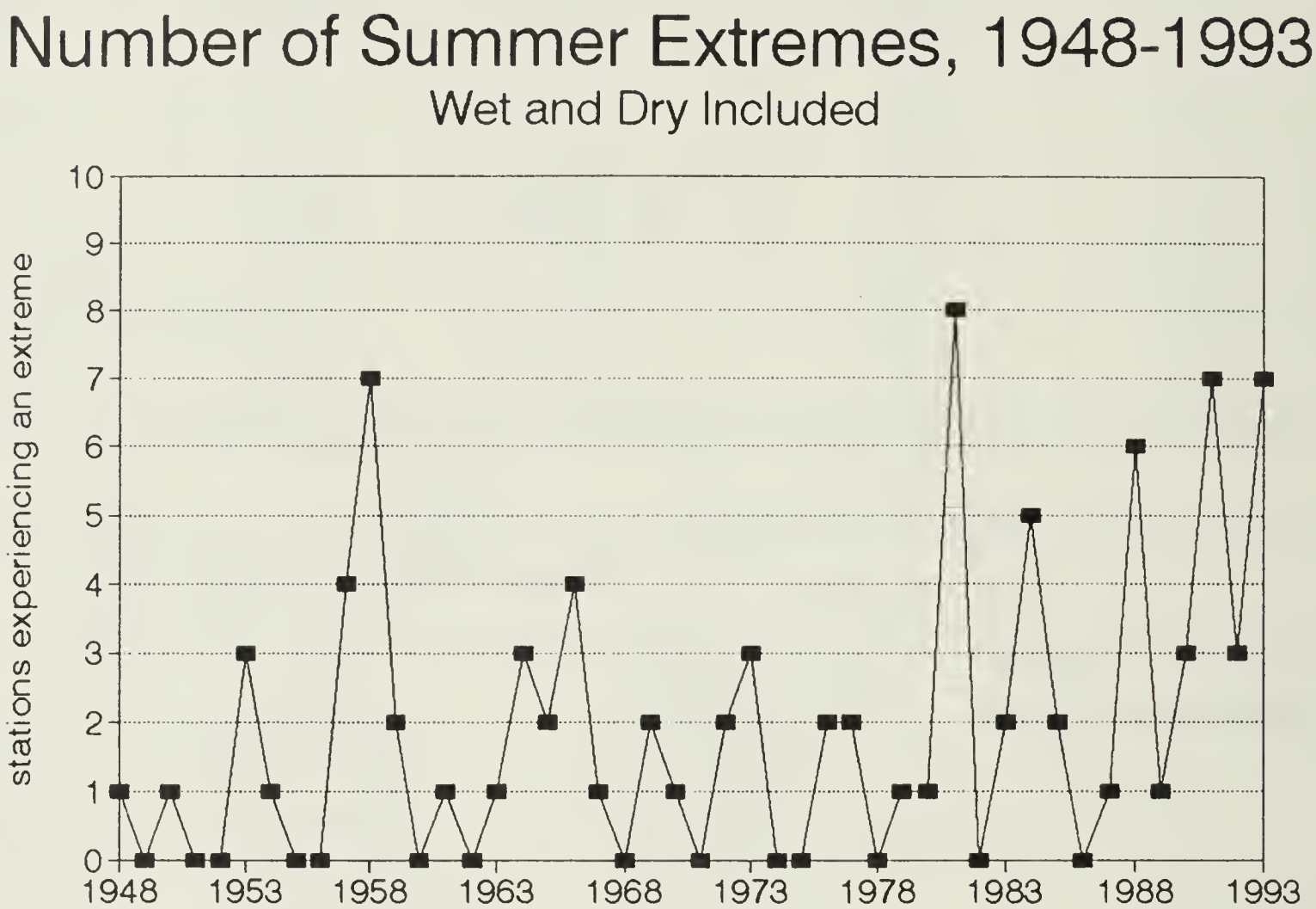


Figure 2. Time series of extreme wet and dry summers based on data from the nine stations.



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Nematode Parasites of a Puerto Rican Tree Frog, *Eleutherodactylus coqui*

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ABSTRACT

Five of ten *Eleutherodactylus coqui* from Puerto Rico were infected with *Parapharyngodon garciae* (Schmidt and Whittaker, 1975) Adamson, 1981. This constitutes the first report of this pharyngodonid nematode in *E. coqui* and the second from leptodactylid frogs. One tree frog was infected with a female *Aplectana* sp. Specific identification of this cosmocercid nematode could not be determined in the absence of a male.

INTRODUCTION

A review of the literature concerning nematode parasites of tree frogs from Puerto Rico revealed a single report (Schmidt and Whittaker, 1975) on the intestinal nematodes of *Eleutherodactylus* spp. We report a new host record of a pharyngodonid nematode in *Eleutherodactylus coqui* Thomas, 1966, from that island.

MATERIALS AND METHODS

Ten *Eleutherodactylus coqui* and one *E. antillensis* Reinhardt an Lutken, 1863, collected at Carr. 3362 k.m.3.6, Guama, Puerto Rico were examined for helminths. Nematodes detected in the large intestines of six frogs were fixed in steaming acetic alcohol (1 part glacial acetic acid and 3 parts 95% ethanol) and cleaned for study in glycerine. Measurements are in micrometers unless otherwise indicated, the range being followed by the mean in parentheses. Voucher specimens have been deposited in the United States National Museum (USNM) Helminthological Collection, Beltsville, Maryland as indicated. Frogs were deposited in the Southern Illinois University at Carbondale (SIUC) Herpetological Collection, Carbondale, Illinois.

RESULTS AND DISCUSSION

Eight mature and four immature females and two mature male pharyngodonid (Oxyurida) nematodes were found in the large intestine of five of ten coquies, *Eleutherodactylus coqui*. In addition, one of the ten coquies contained one female cosmocercid (*Ascaridida*) nematode. The pharyngodonid nematodes agree with the description of *Parapharyngodon garciae* (Schmidt and Whittaker, 1975) Adamson, 1981. *E. antillensis* was found negative for nematodes.

Parapharyngodon garciae

Dimensions: females (N=8), Body 4.4 to 6.1 mm (4.8) long by 400 to 600 (509) wide at vulva; buccal cavity 10 to 15 (13) deep by 11 to 15 (12) wide; esophagus 550 to 780 (664) long, esophageal bulb 114 to 143 (124) long by 136 to 160 (147) wide; nerve ring 300 to 400 (348) from anterior end; excretory pore 0.95 to 1.2 (1.0) mm from anterior end; tail 187 to 320 (251) long; eggs 70 to 81 (77) long by 37 to 46 (42) wide; male (N=1), Body 1.2 mm long by 120 wide; buccal cavity 10 deep by 10 wide; esophagus including bulb 110 long; esophageal bulb only 66 long by 57 wide, nerve ring from anterior end 92; excretory pore from anterior end 90; tail spike 51 long; spicule 33 long. Specimens deposited: USNM Helm. Coll. No. 84025-84028.

Parapharyngodon garciae was reported by Schmidt and Whittaker (1975) as *Thelandros* (*Parapharyngodon*) *garciai*. They considered *Thelandros* Wedl, 1862, to comprise two subgenera, namely *Thelandros* in which the male lacks lateral alae and *Parapharyngodon* Chatterjee, 1933, in which lateral alae are present on males. Adamson (1981), however, considered *Parapharyngodon* a valid genus and transferred *Thelandros* (*P.*) *garciai* to *Parapharyngodon* and noted that *Parapharyngodon* spp. occur in insectivorous reptiles and amphibians whereas *Thelandros* spp. are essentially parasites of herbivorous and omnivorous reptiles. Adamson and Nasher (1985) restricted the definition of *Thelandros* to include only those species in which the pre- and adanal papillae are pedunculated and the opening to the spicular pouch is markedly postanal while in *Parapharyngodon* the pre- and adanal papillae are sessile and the spicular pouch opens into the cloaca. Baker (1987) listed thirty-three species of *Parapharyngodon* occurring in amphibians and reptiles. *Parapharyngodon garciae* is the only species of *Parapharyngodon* reported from leptodactylid anurans of Puerto Rico and until the present report was restricted to *Eleutherodactylus portoricensis* Schmidt, 1927, and to *E. antillensis* . The finding of *P. garciae* in *E. coqui* in the present report constitutes a new host record and the second report of this helminth in tree frogs from this locality. To our knowledge, *Poekilostrongylus puertoricensis* Schmidt and Whittaker, 1975, is the only nematode previously reported from *E. coqui*.

***Aplectana* sp.**

A single female *Aplectana* was found in the large intestine of one coqui. Specific identification could not be determined in the absence of a male. Schmidt and Whittaker (1975) also reported females of two species of *Aplectana* from the large intestines of *Eleutherodactylus locustus* Schmidt, 1920, *E. richmondi* Stejneger, 1904, and *E. coqui*. Likewise, specific identification could not be determined in the absence of males. Specimens deposited: USNM Helm. Coll. No. 84029.

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We thank Andrew and Robin Bruckner, Department of Marine Sciences, University of Puerto Rico for their help in collecting specimens of coquies and Larry Buckley and Dr. Ronald Brandon, Department of Zoology, Southern Illinois University Carbondale for confirming identifications and deposit of frogs in the SIUC Herpetological Collection.

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Recently Discovered Populations of Eastern Woodrats (*Neotoma floridana*) in Southern Illinois

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ABSTRACT

Until recently it was believed that the population of eastern woodrats (*Neotoma floridana*) in Pine Hills, Union County, Illinois, represented the only extant population remaining in the state. Trapping at sites formerly occupied by woodrats and in areas with suitable habitat resulted in the documentation of additional populations at Fountain Bluff, Little Grand Canyon, and Horseshoe Bluff, Jackson County. Woodrats currently are more numerous and have a wider distribution in southern Illinois than previously believed.

INTRODUCTION

Eastern woodrats (*Neotoma floridana*) historically ranged through the eastern United States from New York state across the southeast and central states as far west as Colorado (Hall 1981). Populations have been declining recently throughout the species' range. In the northeastern United States, woodrat populations are believed to be adversely affected by reduced habitat availability and a nematode parasite, *Baylisascaris procyonis*, found in raccoons (*Procyon lotor*) (Woodrat Recovery Workshop 1993). Woodrats are an intermediate host for *B. procyonis* and may ingest the nematode eggs while collecting animal feces (Birch et al. 1994). Infection leads to lethargy, loss of muscle control, and eventual death (Kazacos et al. 1981, Kazacos and Boyce 1989).

The Illinois woodrat (*N. f. illinoensis*), found in southern Illinois, Missouri, Arkansas, Alabama, Mississippi, and western Kentucky and Tennessee, currently is listed as endangered in Illinois (Herkert 1992). Based on the presence of old nest sites and woodrat molars, woodrats inhabited numerous sites throughout the Shawnee National Forest in the past (Nawrot 1974, Nawrot and Klimstra 1976). Only three populations remained in Illinois by the 1960's: Pine Hills, in Union County, and two sites in Jackson County; Fountain Bluff and Horseshoe Bluff (Crim 1961). By 1974, the Horseshoe Bluff population was extirpated and only three individuals could be found at Fountain Bluff

(Nawrot and Klimstra 1976). Since the late 1970's it was believed that the only extant population of woodrats remaining in the state was located at Pine Hills, in southwestern Illinois (Todd Fink, Illinois Department of Conservation Natural Heritage Biologist, personal communication). Woodrat population density continued to decline at Pine Hills; Nawrot (1974) suggested a "liberal" estimate of 50-75 individuals remained. The Illinois Department of Conservation conducted periodic surveys for signs of activity at nest sites at Pine Hills (Todd Fink, unpublished data) since 1973. West (1986) estimated that 15-30 woodrats inhabited Pine Hills based on the number of presumed active nests. A 3-year live-trapping investigation of the Pine Hills woodrat population was initiated in July 1993. Associated with this effort was exploratory live-trapping at several previously inhabited sites, and areas with appropriate bluff habitat. Since January 1994, we have documented the occurrence of woodrats at three additional sites in Illinois: Fountain Bluff, Little Grand Canyon, and Horseshoe Bluff, Jackson County.

STUDY AREAS

Pine Hills

Pine Hills is composed of north-south oriented limestone bluffs that extend 8.8 km and average 24.4 m above the flood plain (Baskett 1925, Weller and Ekblaw 1940). Woodrats have been trapped along the south- and west-facing bluffs located in sections 9, 16, 21, and 28, T. 11 S, R. 3 W.

Fountain Bluff

Fountain Bluff is located 8 km northwest of Pine Hills. The lower strata of this isolated ridge are composed of limestone, although thick layers of sandstone form the upper strata. The bluffs reach 61 m above the Mississippi River (Poor 1925). Woodrats have been located in section 36, T. 9 S, R. 4 W, and section 31, T. 9 S, R. 3 W.

Horseshoe Bluff

Woodrats have been captured at Horseshoe Bluff, a stretch of west-facing sandstone bluffs and fallen boulders located in sections 11 and 14, T. 10 S, R. 3 W. Horseshoe Bluff is located about 11 km north of the trapping site at Pine Hills.

Little Grand Canyon

The Little Grand Canyon area is composed of both limestone bluffs and sandstone canyons that have been eroded by streams. It is located about 1 km north of Horseshoe Bluff and about 8 km east of Fountain Bluff. Woodrats have been trapped in sections 2 and 11, T. 10 S, R. 3 W.

MATERIALS AND METHODS

Tomahawk wire mesh live-traps (16.5 x 16.5 x 48 cm) were set in appropriate habitats at all sites, primarily limestone or sandstone bluffs or outcrops with cracks, depressions, ledges, and overhanging areas. Traps were baited with cracked corn and sunflower seeds and placed as often as possible at sites with woodrat sign: stick nests, fecal droppings, feeding debris, and/or tracks. Polyester stuffing was provided for bedding. Each captured animal was tagged with two individually numbered Monel #3 ear tags. Mass (to the nearest gram), sex, and reproductive condition were recorded. Age class (juvenile,

subadult, adult) was determined on the basis of sexual maturity, body mass, and pelage color (Wiley 1980).

RESULTS

Pine Hills

Trapping at Pine Hills began in July 1993. A trapping schedule of 40 traps set for 3 nights every 3 to 4 weeks was followed. Although only part of the available habitat has been sampled, as of August 1994, 135 individuals (Table 1) have been captured 675 times in 1800 trap nights (36.0% trap success rate). The sex and age ratios of the trapped individuals change seasonally as most litters are produced in the spring and juveniles disperse in the fall. As traps have been placed at new locations within Pine Hills, new woodrats have been taken. This suggests a substantially greater population exists than previously anticipated.

Fountain Bluff

On 3-4 January 1994, 7 woodrats were captured in 24 trapnights. Large stick nests and latrine sites were present at the trapping location. From February through April 1994, exploratory trapping was conducted at additional locations throughout Fountain Bluff. In June 1994 a trapping schedule of 35 traps set for three nights every 3 to 4 weeks was established. As of July 1994, 19 individuals (Table 2) have been captured 29 times in 287 trap nights (10.1% trap success rate). In addition to the established trapping sites, we are continuing exploratory trapping.

Little Grand Canyon

On 10 July 1994, 3 woodrats were captured in 14 traps set at two sites. Stick nests, mast shells, and fresh scat were present at both sites.

Horseshoe Bluff

On 27 July 1994, 3 woodrats were captured in 12 traps set. Although no nests were observed, the bluff and forest habitat of Horseshoe Bluff was suitable to support woodrats. Mast shells, tracks, and leaves in rock depressions were the only signs that woodrats were present in the area.

DISCUSSION

Past assessment of the Pine Hills woodrat population determined the "activity" of nest sites by the presence of fresh vegetation cuttings in the nests, signs of recent building, and fecal droppings. In monthly trapping at Pine Hills from July 1993 through August 1994 very few active nests actually contained fresh cuttings. Many stick piles where woodrats were trapped appeared to be abandoned. Woodrat nests at Pine Hills do not always fit the usual description of a large mound of sticks (Hall 1955). Nests may be primarily composed of dead leaves and bark as well as sticks. Because numerous crevices and deep fissures are present in the bluffs of Union and Jackson Counties, it is possible that many more woodrat populations exist without externally visible signs such as stick nests. Therefore, in order to determine whether woodrats are present at a location that has no visible stick nests, it is necessary to conduct live-trapping. More extensive live-trapping will be conducted at the Little Grand Canyon and Horseshoe Bluff areas to

estimate the number of individuals present. The genetic diversity within and among the four populations currently is being investigated. The occurrence of more woodrat populations than previously known in southern Illinois offers expanded management opportunities for this endangered species.

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Table 1. Age and sex distribution of woodrats captured at Pine Hills, Union County, July, 1993 - August, 1994.

	Male	Female	Total
Juvenile	14	15	29
Subadult	13	25	38
Adult	27	41	68
Total	54	81	135

Table 2. Age and sex distribution of woodrats captured at Fountain Bluff, Jackson County, January, 1994 - July, 1994.

	Male	Female	Total
Juvenile	2	2	4
Subadult	1	4	5
Adult	4	6	10
Total	7	12	19

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Some Aspects Of Raccoon Life History In Lee County, Illinois

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ABSTRACT

Raccoons (*Procyon lotor*) were livetrapped and marked during summers 1990-1993, in mixed wetland, forest, and agricultural habitats on 2 sites, the 656-ha Richardson Wildlife Foundation (RWF) and the 297-ha Amboy area (AA) in Lee County, northcentral Illinois. Males predominated in captures of juveniles through 2 years of age, but females dominated older age classes. Estimated fall densities ranged from 7.5 to 18 raccoons per 100 ha. Yearling female breeding rates averaged 40% (range 25-50%); older females averaged 83% (range 50-100%). The age structure of females indicated that yearling breeding contributed only about 20% of the production of young on both study areas. Annual recovery rates (sum of death and dispersal) for sexes combined were 0.57 and 0.18 for juveniles and 0.61 and 0.66 for adults on the RWF during 1990-1991 and 1991-1992, respectively. For AA raccoons, adult recovery rates were 0.64 for 1990-1991; for juveniles, they were 0.53 and 0.42 for 1990-1991 and 1991-1992, respectively. During the growing season, raccoons were most abundant in water associated habitats. They avoided grasslands, restored and native prairies as well as corn and soybean fields. Current exploitation levels on both study areas were below the threshold of sustainability postulated for raccoons in the Midwest and raccoon numbers increased during our study. Low pelt prices have reduced human exploitation, and annual postweaning survival exceeded 60% during our study.

INTRODUCTION

There have been few studies of raccoon populations in Illinois. Sanderson and Hubert (1981) reported on the demographic characteristics of raccoons harvested by hunters and trappers in Illinois. They found that sex ratios of harvested raccoons favored males, that juveniles made up about two-thirds of the harvest, and that parous females averaged about 3.5 young per litter. Based on these data collected over 25 years (1955-1980), they concluded there had been little demographic change in the raccoon population in Illinois during that interval. Ellis (1964) used radio tracking to investigate home range and movements of 7 raccoons in east-central Illinois woodlots. Home ranges averaged 55 ha in a 600 ha woodlot and 68 ha in a 24 ha woodlot.

We studied raccoon population dynamics and summer habitat selection of raccoons from the fall of 1990 until the early fall of 1993 using livetrapping on 2 sites in Lee County, Illinois. Our objectives were to (1) investigate current raccoon exploitation rates in northern Illinois and; (2) contribute to life history data base of raccoons in Illinois.

METHODS

Both study areas were privately owned. The 656-ha Richardson Wildlife Foundation (RWF) was a refuge from hunting, but 1 person trapped in 1992 and 1993. Habitat composition on the RWF was 60% cropland (corn, soybeans, sunflowers, forage crops), 16% restored prairie, 13% early successional woodland, 10% wetland, and 2% miscellaneous cover (buildings, roads, etc.). The 297-ha Amboy Area (AA), open each year to both hunting and trapping, was comprised of 51% woodland, 24% pasture, 12% cropland, 6% wetland, 5% miscellaneous cover, and 2% restored prairie.

Raccoons were livetrapped during 2- to 3-week periods on each study area during August-October 1990 and June-September 1991-1993. We also livetrapped for 8-day periods in March 1992 and 1993 on the RWF. Traps were set throughout each site in habitats likely to harbor raccoons during 1990 and 1991 at densities of 1 trap per 25 ha (RWF) and 1 trap per 10 ha (AA). In 1992 and 1993 traps were set in proportion to the available habitat at densities of 1 trap per 14 ha (RWF) and 1 per 10 ha (AA). Captured raccoons were weighed to the nearest 0.1 kg and immobilized using ketamine hydochloride (100 mg/ml, 0.1 cc per 0.45 kg of body weight). Raccoons were then sexed, examined for external parasites and injuries, examined for breeding activity (females pregnant or lactating, males if penis extrusible [Sanderson 1961]), ear tagged with serial-numbered plastic tags, and released after recovery at the trap site. A lower first premolar was extracted from all raccoons ≥1 year for aging using tooth cementum (Grau et al. 1970).

We estimated raccoon numbers each year using the software package CAPTURE (Rexstad and Burnham 1991). Because we made only a few recaptures each trapping period, we used estimators that assume capture probabilities vary by behavioral response to capture (Mb) and by individual animal as well as behavioral response to capture (Mbh). These estimators use the number of unmarked animals captured and do not require large numbers of recaptures to compute a population estimate (Rexstad and Burnham 1991).

We attempted to simulate the effect of fall harvests of males on the subsequent population dynamics of raccoons by removing captured yearling and adult males from the RWF in fall 1990 (N = 7), 1991 (N = 3), and 1992 (N = 14). These males were transported 33 km away to the Green River Conservation area and immediately released.

Raccoon captures were compared among sexes, ages, areas, and years using a contingency table analysis and likelihood ratio chi-square tests assuming that the response rates are the same in each sample (SAS Institute 1994). Seasonal changes in weight were compared for males only (female weights affected by pregnancy and the metabolic demands of nursing young) among areas, ages (yearling vs. adult), and years using analysis of variance (ANOVA). Monthly comparisons of changes in mean weight were made using Tukey-Kramer HSD tests (SAS Institute 1994).

Adult female breeding rates were estimated each year based on whether females were pregnant (palpated fetuses), nursing, or anestrous. Chi-square tests with one degree of freedom were used to compare breeding rates of adults and yearlings, and capture sites.

Grids in both areas were arranged as 1-ha blocks, and each block was assigned a habitat type based on the dominant (≥50%) vegetation present. In both 1992 and 1993, traps were apportioned over each study area using random grid numbers to place traps (maximum number of traps used = 48 on RWF and 28 on AA) according to habitat availability. Chi-square analysis with one degree of freedom was used to compare expected captures based on habitat availability with actual captures in each habitat type.

Annual recovery rates on each study area (combined death and dispersal, September-September) were calculated for juveniles and raccoons ≥1 year, sexes combined, for 1990 and 1991 using the program JOLLY.AGE (Pollock et al. 1990). Sample sizes were too small to separate the sexes on each area. Male raccoons removed from the RWF were not used in the calculation of adult recovery on the RWF. Two X two chi-square tests of independence was used to compare recovery rates among years and age classes.

RESULTS AND DISCUSSION

Population Characteristics

There were 176 and 111 raccoons captured and released on the RWF and AA, respectively. Males predominated in captures on the AA but not on RWF (likelihood ratio chi-square = 12.9, df = 1, P = 0.0003) (Fig. 1). Combining areas, males predominated among juveniles and yearlings and females among adults (likelihood ratio chi-square = 4.6, df = 2, P = 0.09). Sex ratios did not differ among years on either area but we captured proportionally more adults on the AA (likelihood ratio chi-square = 8.1, df = 2, P = 0.02). Combining areas, adults were more common in our captures in 1992 and 1993 compared with 1990 and 1991 (likelihood ratio chi-square = 20.6, df = 6, P = 0.002). More juvenile males were captured on the RWF than on the AA after we removed older males from the RWF, but yearling males were proportionally more abundant on the AA (Fig. 1). The oldest females captured were 10 and 7 years old and the oldest males captured were 5 and 4 years old on the RWF and AA, respectively.

The mean number of raccoons captured/traps set each summer was also used as an index to raccoon abundance on each area. Mean captures per trap set were nearly identical on both areas, averaging 0.041 on the AA and 0.0405 on the RWF (one way ANOVA = 0.0018, df = 1, P = 0.96). However, calculated estimates of raccoon numbers using software program CAPTURE indicated that raccoons were more abundant on the AA, even though raccoons were hunted and trapped on the area (Table 1).

Breeding

Breeding rates for yearling females for both areas combined averaged 40% (N = 20), ranging from 25% (1990, N = 4) to 50% (1992, N = 6). Adult female breeding rates averaged 83% (N = 36), with a range of 50% (1992, N = 2) to 100% (1990, N = 9), and did not differ significantly (P>0.05) among years. Yearlings accounted for about 37% of the females ≥1 year old captured on both study areas. With a lower breeding rate compared

with adults, yearlings contributed less to the total breeding effort in Lee County than in areas where yearlings constitute a higher proportion of the female population (Fiero and Verts 1986). Using the age structure of captured females to estimate potential production of young indicates that yearlings in an average year would contribute only about 20% of the young produced on the study areas during our study.

Stuewer (1943) reported that 53% of yearling females bred in 1 year in Michigan. Fritzell et al. (1985) reported yearling breeding rates between 38% to 77% for raccoons in Missouri and Illinois over a 3-year period, with pregnancy rates greater in Illinois. Adult females averaged a 95% breeding rate in Illinois and 81% in Missouri (range 68-96%) (Fritzell et al. 1985). Yearlings averaged a 62% breeding rate and adults 91% for a 3-year period in Iowa (Glueck 1985). Payne and Root (1986) found that 32% of the yearling females and 91% of the adults bred in southwestern Wisconsin over a 2-year period.

Movements

Movements between trapping periods were noted for 9 raccoons, 8 juveniles and 1 adult. Three juveniles and an adult moved <900 m between the capture site and site of recovery, and a juvenile male moved 5 km NE of the RWF, all within 1 year of capture. A juvenile male dispersed 26 km north of the RWF and was killed on the highway 2 years after capture. Another juvenile male dispersed 41 km SW of the RWF and was killed on the highway 16 months after capture. Two juveniles, a male and female, dispersed 2.5 km from the AA and RWF, respectively, both within 2 months of capture.

Body Weights

Raccoons were weighed at first capture during March (RWF only) and May through September (both areas). Combining data from both study areas, adult male body weights were similar among years ($F = 1.6$, $df = 3$, $P = 0.16$) and areas ($F = 0.004$, $df = 1$, $P = 0.99$). Body weights (mean ± S.E.) of adult males, areas and years combined, were significantly heavier ($F = 3.8$, $df = 6$, $P = 0.004$) in September (7.2 ± 0.31 kg, N = 9) compared with March (5.7 ± 0.35 kg, N = 7, RWF only), June (6.4 ± 0.29 kg, N = 11), and July (6.2 ± 0.42 kg, N = 5). Adult male weights did not differ among June , July, and August (6.9 ± 0.26 kg, N = 13) captures. Yearling males gained weight ($F = 4.9$, $df = 6$, $P = 0.008$) between March (4.7 ± 0.27 kg, N = 8) and June (5.5 ± 0.18 kg, N = 18) and July (5.4 ± 0.27 kg, N = 8).

Lipid deposition and weight gain occurs in temperate raccoons from mid-July until December (Lotze and Anderson 1979, Hanni and Millar 1993, Mech et al. 1968, Zeveloff and Doerr 1985). Sanderson and Hubert (1981) found November-December males from north-central Illinois to average 8.8 kg for adults and 5.4 kg for juveniles, while adult females averaged 7.6 kg for parous females and 7.5 kg for nulliparous females, significantly lighter than males in late fall (Sanderson and Hubert 1981).

Recovery Rates

Recovery rates were the product of deaths and dispersals on each area. The annual juvenile recovery rate (proportion recovered on the study area = 0.57) of RWF raccoons was comparable to the adult recovery rate (0.61) for 1990-1991, but the juvenile recovery rate was lower than the adult tag recovery in 1991-1992 (juvenile = 0.18, adult = 0.66, (2X2 chi-square test, $X^2 = 3.67$, $P<0.05$). The juvenile recovery rate of AA raccoons was 0.53

for 1990-1991 and 0.42 for 1991-1992. The tag recovery of 0.64 for adults on the AA for 1990-1991 did not differ from the juvenile tag recovery, but recaptures were too few to calculate an adult recovery rate for 1991-1992.

Juvenile tag recovery did not differ between areas for 1990-1991 or 1991-1992, even though the juvenile recovery rate was considerably higher on the AA than on the RWF for 1991-92, 0.42 vs. 0.18 ($X^2 = 1.2$, df = 1, P = 0.30). There was no indication that removal of older males significantly improved recruitment of juvenile and yearling raccoons into the RWF population. Sanderson (1987), using productivity and sex-age data collected from Illinois hunters and trappers for 1981-1984, estimated juvenile male annual survival at 0.28. Annual survival of after-birth-year males (0.58) exceeded that of after-birth-year females (0.42) (Sanderson 1987). Annual survival of adult raccoons averaged 0.68 for 2 areas in an epizootic rabies area in Pennsylvania (Brown et al. 1990).

All but 7 of 24 known deaths of raccoons marked on the RWF were human induced; 11 raccoons were trapped, 5 were killed by vehicles, 7 died of disease, and 1 was killed by a farm dog. There were 17 known deaths reported for raccoons marked on the AA; and only 2 of these were natural deaths. Twelve were shot by hunters, 2 died of disease, and 1 each died because of trapping, a highway accident, and a farm dog. Trapping accounted for 45% of the deaths among RWF raccoons, and hunting and trapping combined accounted for 76% of the deaths among AA raccoons. Hasbrouck et al. (1992) reported hunting and trapping accounted for 71% of the deaths of raccoons in Iowa.

Habitat Selection

During the growing seasons of 1992 and 1993, water-associated habitats, particularly emergent wetlands, attracted raccoons on both study areas. On the RWF in summer raccoons were captured more often in upland forest and around ponds and wetlands and less often in sunflower fields, soybeans, hayfields, and prairies (Table 2). On the AA, raccoons avoided pastures and corn fields and were captured more often in wet forest, and around ponds, wetlands, and marshes (Table 2).

CONCLUSIONS

Our estimates of 7-18 raccoons per 100 ha on each area fall within reported densities in North America. Raccoons averaged 10 per 100 ha in upland hardwoods in Virginia (Hallett et al. 1991) whereas Kennedy et al. (1991) estimated 13 raccoons per 100 ha of lowland forest in Tennessee. Conner and Labisky (1985) estimated 12 raccoons per 100 ha for a site in northern Florida. The highest published densities of raccoons were 167 raccoons removed from 41 ha on a lowland site in Missouri (Twitchell and Dill 1949) and 1 raccoon per 0.3 ha in an area of mixed agriculture and forest in Quebec (Riverst and Bergeron 1981).

Based upon age-specific life expectancy estimates and population age structure, longevity of raccoons in Lee County, Illinois, was <3 years. Females currently outlive males on our study areas. Although not presented here because of low sample size, male recovery rates were lower than females on both study areas, a reflection of higher dispersal rates for males (Nixon et al. 1993) as well as a higher probability of capture by hunters and trappers (Sanderson and Hubert 1981). Polygonous mating also often results in a higher

mortality of males as a result of longer and more frequent seasonal movements in inclement winter weather and conflicts with other males. Sexual dimorphism in size favoring males (Sanderson 1987) and female-biased sex ratios in adult age classes are often characteristic of a polygnous mating system (Ritke and Kennedy 1993).

Raccoons were more abundant in summer on the AA area apparently in response to the greater amount of wetland associated habitats present on the area. Wetand habitat covered nearly 20% of the AA compared to only 9% of the RWF (Table 2) and these additional areas attracted more raccoons. Leberg and Kennedy (1988) found that raccoon densities were highest in bottomland deciduous forests in west Tennessee and that wetland habitats supported more females and young than upland habitats. Fritzell (1978a) observed that raccoons favored wetland-associated habitats in spring and summer in North Dakota. Glueck (1985) found lowland forest to be the favored habitat for raccoons in Iowa, with the use of upland forest being important only in the fall. Leberg and Kennedy (1988) found juveniles more abundant in bottomland habitat and attributed this difference to habitat -specific reproduction, with more young produced in wetlands. We found juveniles more abundant on the RWF, although wetland associated habitats were more abundant on the AA (Table 2).

There is conflicting evidence for territorial behavior among male raccoons. Fritzell (1978b) reported territorial behavior among males in North Dakota, but Johnson (1970) in Alabama and Allsbrooks and Kennedy (1987) in Tennessee reported overlapping ranges. We found that both sexes had some sharing of ranges during the summer months. Fifty-four of 98 males (55%) were captured in the same trap or within the same hectare as another male during the same summer. Of these captures, 6 were of 2 yearlings, 12 were of an adult and a yearling, and 12 were of 2 adults. For 69 females, only 20 (29%) were captured in the same trap or hectare as another female during the same summer of trapping. Of these captures, 3 were of 2 yearlings, 5 were of an adult and a yearling, and only 2 were of 2 adults. These capture rates were different (Fisher's exact test $P = 0.0009$) between the sexes and suggest that females may be less tolerant of same sex conspecifics than males, at least during the litter-rearing period in summer. Females may also be more tolerant of yearling females than of older females within their postpartum ranges. These yearlings may also have been related to the adult female and shared portions of her range, although philopatry has not been specifically reported for the raccoon. Indeed, both sexes may mutually avoid one other during the summer (Mech et al. 1966, Johnson 1970). Fritzell (1978b) found extensive summer range overlap among parous females in North Dakota, but these females avoided contact with other raccoons except for their young. Twitchell and Dill (1949) removed more than 100 raccoons from dens in Missouri and found males more likely to den with others (32/40, 80%) than were females (28/60, 47%).

Apparently our male removals from RWF were too small (average = 8 per year) to affect male recruitment from resident young or immigrants, based on a between-area comparison of recovery rates of males marked as juveniles and the recruitment rates of yearlings after male removals (total captures of yearlings). The proportion of males captured each year did not differ between areas either before or after male removal from RWF, ranging between 40% (RWF 1990) and 74% (AA 1991).

Total known losses of captured males from the RWF (assuming the males removed each year were tagged and in the population each fall) totaled 43% (7/16), 17% (4/23), and 49% (18/37) for 1990, 1991, and 1992, respectively. Numbers of trap-susceptible males were not affected by these losses, and annual recovery rates of adults averaged about 60% on both areas during 1990-1991. Clark et al. (1989) estimated a maximum sustainable potential harvest of 41% of preharvest numbers for raccoons in Iowa. Sanderson (1987) estimated sustainable harvest levels ranging from 49% to 59% of the total population for 3 levels of fecundity for raccoons in west-central Illinois. However, harvests of juveniles could be considerably higher than these levels, up to 76% for males and up to 60% for females in high-fecundity populations. Sustainable harvest levels for adults were considerably lower, between 29% and 33% for males and 46% and 54% for females (Sanderson 1987). Known losses of males exceeded these levels for 1990 and 1992, but recruitment of males was sufficient to sustain the male population.

These data were collected at a time of low pelt prices and reduced harvests compared to the long-term mean for raccoon harvests in Illinois (Bluett and Hubert 1992). The low harvests and generally mild winters allowed raccoon numbers to increase during the study on both study areas. Postweaning annual mortality levels appear to be <40% from all causes, based on recoveries of marked raccoons in northern (this study) and west-central Illinois (Nixon et al. 1993).

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Figure 1. Sex and age of raccoons captured on the Richardson Wildlife Foundation (RWF) and the Amboy Area (AA), Lee County, Illinois, 1990-1993.

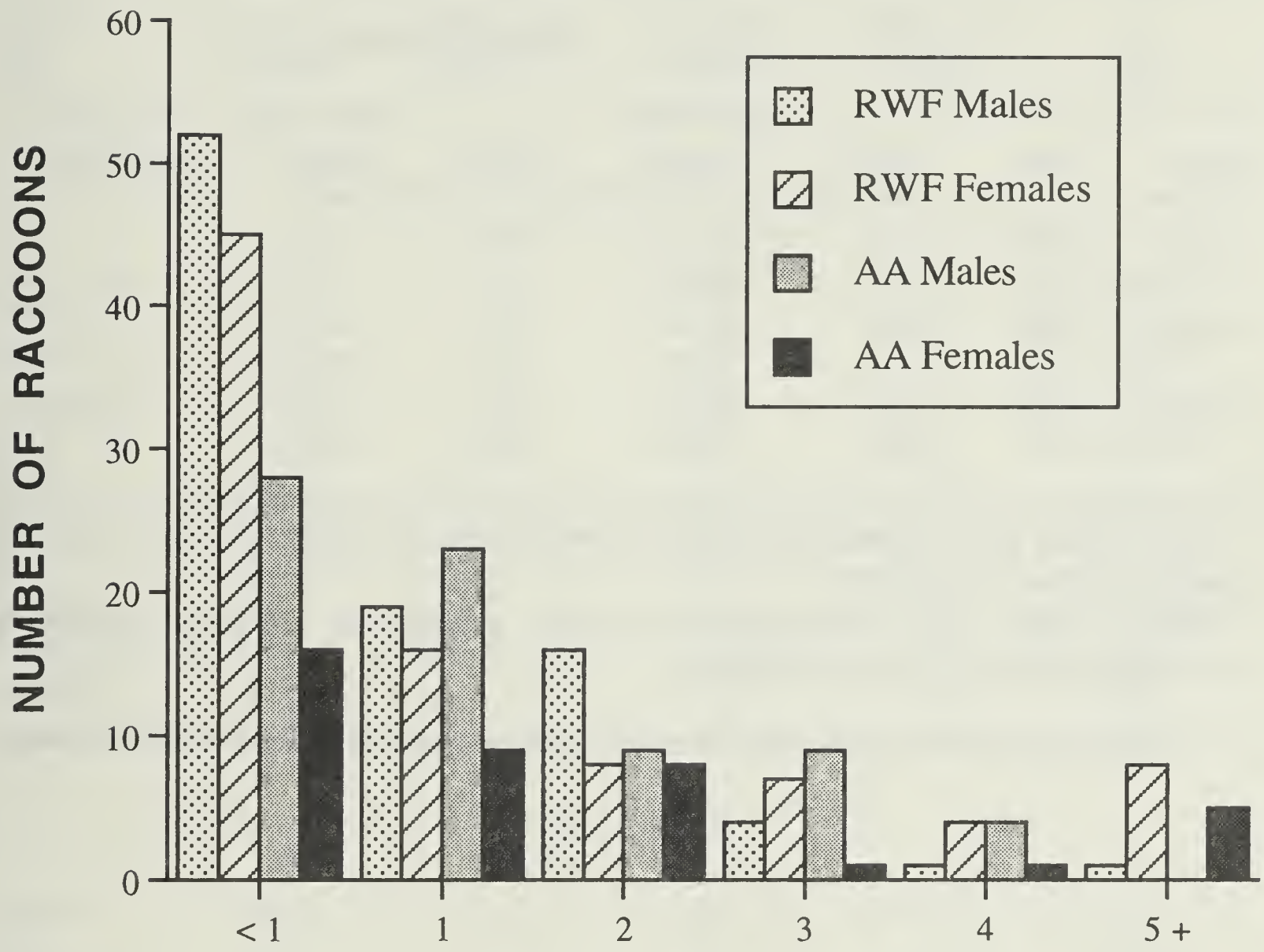

Table 1. Estimated number of raccoons present in late summer on the Richardson Wildlife Foundation (RWF) and Amboy Area (AA), Lee County, Illinois, 1990-1992.

		Capture Estimates				
Year	Area	Mb[a]	95% Conf. Interval	Mbh[b]	95% Conf. Interval	Aver. No. Per 100 Ha
1990	RWF	49	39-93	40	37-67	7
	AA	28	19-93	18	–	8
1991	RWF	28	26-42	28	26-42	4
	AA	38	30-77	36	28-67	12
1992	RWF	42	36-68	42	36-68	6
	AA	51	41-70	55	44-81	18

[a] Mb = Model where capture probabilities change due to behavioral response from first capture (Pollock et al. 1990).

[b] Mbh = Model where heterogeneity of capture probabilities are found and capture probabilities change with capture history.

Table 2. Observed and expected raccoon captures on the Richardson Wildlife Foundation and Amboy Area with traps set in proportion to habitat availability during summer-early fall 1992 and 1993. P-Values are for one degree of freedom.

Habitat type	Proportion available	Observed captures	Expected captures	Chi-square values	P value
		RICHARDSON WILDLIFE FOUNDATION			
Corn	0.28	29	31.8	1.2	0.30
Grasses	0.14	2	16.0	16.6	0.0005
Prairie	0.14	6	15.3	8.1	0.005
Soybeans	0.09	1	9.6	9.7	0.005
Forest	0.06	21	7.0	28.6	0.0005
Pines	0.06	9	7.0	0.7	0.40
Ponds	0.04	15	4.9	18.9	0.0005
Oats	0.04	0	4.6	5.1	0.025
Wetlands	0.04	28	4.5	125.6	0.0005
Sunflowers	0.03	0	3.2	3.9	0.05
Buildings	0.01	0	1.2	1.6	0.30
Wet forest	0.01	1	1.1	1.4	0.30
		AMBOY AREA			
Pasture	0.24	5	11.1	5.1	0.05
Pines	0.18	5	8.5	2.1	0.20
Wet forest	0.14	17	6.7	17.5	0.0005
Bur Oak	0.13	5	6.2	0.4	0.60
Corn	0.07	0	3.4	3.9	0.05
Soybeans	0.04	0	2.0	2.3	0.20
Succ. forest	0.04	1	1.8	0.5	0.50
Ponds	0.04	5	1.7	6.4	0.025
Prairie	0.02	0	0.9	1.0	0.40
Oats	0.02	0	0.7	0.8	0.40
Wetlands	0.01	5	0.6	25.4	0.0005
Marsh	0.01	3	0.5	12.5	0.0005

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Notes on Road-Killed Snakes and Their Implications on Habitat Modification Due to Summer Flooding on the Mississippi River in West Central Illinois

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ABSTRACT

Beginning 6 October 1993 an increase in the number of road-killed (DOR) snakes was noted along Illinois Route 100 in Jersey and Madison counties, Illinois. A total of 113 snakes representing 12 species including *Nerodia sipedon* (n = 29), *Thamnophis sirtalis* (n = 22), *Elaphe obsoleta* (n = 13), *Nerodia erythrogaster* (n = 13), *Regina grahamii* (n = 13), *Nerodia rhombifer* (n = 10), *Elaphe vulpina* (n = 6), *Lampropeltis calligaster* (n = 3), *Lampropeltis getula* (n = 1), *Pituophis melanoleucus* (n = 1), *Storeria dekayi wrightorum* (n = 1), and *Thamnophis proximus* (n = 1) were collected over the 3,402 km of road searched (0.033 snakes/km or 30.1 km/snake). Eighty-six (76%) snakes were collected on five of the 21 dates. Snake counts for these five dates ranged between 12 and 25 snakes per date (17.2 snakes/date or 0.106 snakes/km). The number of snakes collected on the other 16 dates ranged between 0 and 6 snakes per date (1.7 snakes/day or 0.010 snakes/km). Date of collection, daily high and low temperatures, river stage at Grafton and Alton, and precipitation were not correlated with total snake numbers, number of terrestrial species, or number of aquatic species. Correlations between one or more of the abiotic factors and numbers of individual species were found with daily high and low temperatures and river stages being the most frequently associated variables. Principal component analysis indicated that measures of temperature are the best overall predictor of snake movements as measured by the number of DOR snakes in this particular instance. The unusual snake movements observed are thought to be due to the large flood event during the summer of 1993. The flood altered the nature of the rip rap along the road by depositing silt in the interspaces between the individual rocks that make up the rip rap. These snakes may have hibernated within the rip rap and their fall movements to hibernacula went unobserved because they did not cross the road to reach suitable over-wintering sites. When flooding made these hibernacula unsuitable, the snakes were forced to cross the road to find other sites for hibernation.

INTRODUCTION

Illinois Route 100 is a busy, 4-lane divided highway locally known as the Great River Road. For 21 km between Grafton (population 1,000, Jersey County) and Alton (population 36,000, Madison County), Illinois, the road lies between the Mississippi

River and limestone/dolomite bluffs. Except where it crosses Piasa Creek 9 km NW of Alton, the road is bordered by the Mississippi River on one side and the bluffs on the other. Between Grafton and Alton, the road trends NW-SE or W-E due to the river bend. North of Grafton, the road trends N-S and follows the course of the Illinois River. At this point it is not immediately adjacent to that river except at scattered locations.

For almost two years, I have traveled between Elsah and Alton, Illinois, on a daily basis to and from the Illinois Natural History Survey field station south of Alton. During this time I occasionally have noted road-killed (hereafter called DOR) snakes along this route. Beginning 6 October 1993, I noted an increase in the number of DOR snakes. A high level of snake activity along this road is unusual in my experience and in the opinion of other herpetologists (R. Axtell, C. Phillips, O. Sexton pers. comm.) with more experience traveling this road. Geographic distribution records for selected specimens were previously reported by Tucker (1994). The present paper summarizes data on those and the other snakes collected.

MATERIALS AND METHODS

Except for October 26, I traveled the road (Fig. 1) daily between October 7 and October 28 from Alton to Deer Plain Ferry (locally known as the Brussels Ferry) and then back again (= one trip). Each trip covered a road distance of 54 km. I made three trips each day with the first beginning between 1330 and 1630 h., the second between 2000 and 2200 h., and the third between 0200 and 0400 h., Central Standard Time. Speed varied between 24 and 56 km/hour. I recorded the distance from each DOR snake to the Alton water treatment plant at the western edge of Alton. All specimens for which snout to vent length (SVL) could be measured were preserved and are deposited in the collections of the Illinois Natural History Survey (INHS 10999-11109). I identified each specimen to species (Smith, 1961), determined sex by eversion of hemipenes during preservation, and measured SVL to the nearest mm after fixation and preservation. L. E. Brown, Department of Biological Sciences, Illinois State University and C. Phillips, Illinois Natural History Survey confirmed identifications for selected specimens of each species. I recorded the high and low temperatures and precipitation at Alton, and the river stages at both Alton and Grafton from daily summaries compiled by the National Weather Service and published in the Alton Telegraph. Statistical tests were performed with the SAS System computer programs (SAS Institute, 1988). Because some abiotic variables did not meet all assumptions of normality, nonparametric Spearman rank correlation was used for correlation analysis. For comparisons of male and female SVL within species, I used a one-way analysis of variance (ANOVA) with Tukey's *t*-test.

RESULTS

I collected 113 snakes representing 12 species (Table 1) over the 3,402 km of road searched (0.033 snakes/km or 30.1 km/snake). The number of snakes found per km of road between the start point and end point of each trip was 0.066 snakes/km or 0.198 snakes/km/day. The direction of snake movement appeared to be from the river towards the bluffs since most DORs were on the river side of the highway. All five specimens found alive were crawling away from the river and towards the bluffs.

More females were found DOR in two of the four most commonly collected genera. Sex ratios (male:female, chi square value, p) for the four most commonly collected genera were 5:14, 4.3, $p < 0.05$ for *Elaphe*; 27:25, 0.08, $p > 0.05$ for *Nerodia*, 4:9, 1.92, $p > 0.05$ for *Regina*, and 6:17, 5.26, $p < 0.05$ for *Thamnophis*.

For the six most commonly collected species mean SVL for males was not statistically different ($p > 0.05$) from females. Mean SVL by sex in mm (males : females) for these six species were *E. obsoleta* (851.7 : 879.6), *N. erythrogaster* (580.8 : 737.1), *N. rhombifer* (510.8 : 628.5), *N. sipedon* (462.8 : 515.1), *R. grahamii* (516.5 : 575.6), and *T. sirtalis* (430.2 : 523.9). However, in each species, females found DOR were larger than males which seems unlikely to be due to chance alone. No data were available on populations of these species from the study area so it cannot be determined if the snakes observed DOR were an unbiased sample of the populations bordering the road.

Distribution of DORs was not uniform over the 27 km of roadway surveyed (Fig. 1). The number of snakes collected formed peaks at km 1, 6, 9, 15, and 26. The peak near km 15 was due to a large number of *T. sirtalis* specimens collected in that area. The drop off at km 21 occurred at Grafton and could be associated with increased human disturbance along with the fact that the road is not as close to the Mississippi River once the confluence with the Illinois River at Grafton is reached. The road does not closely border the Illinois River until it reaches the ferry near km 27. At this point, the number of DORs rebounded. The largest number of specimens of any species at any particular km was eight (*T. sirtalis*) at km 15.

Snake movement as reflected by DOR counts per date was not uniform (Fig. 2). Eighty-six (76%) snakes were collected on five of 21 days. Snake counts for these five days ranged between 12 and 25 snakes per day (mean = 17.2 snakes/day) or 0.106 snakes/km for the trips made on those days. For all days of the study, the mean was 5.38 snakes/day (SD = 7.54). Days with 12 or more snakes departed significantly ($p < 0.01$) from a Poisson distribution. The number of snakes collected on the other 16 days ranged between 0 and 6 snakes per date (mean = 1.7 snakes/day) or 0.010 snakes/km for the trips made on those days. The distribution for total snake numbers per day also departed significantly from a normal distribution (Shapiro-Wilk test, $p < 0.0001$) because it was skewed (skewness measure = 1.78) with positive kurtosis (kurtosis measure = 2.37) by the five days with high numbers of snakes collected.

The first and last date of collection of the six most commonly encountered species during the study period were as follows: *E. obsoleta* 10 to 25 October; *N. erythrogaster* and *N. rhombifer* 7 to 17 October; *N. sipedon* 7 to 27 October; *R. grahamii* 7 to 21 October; and *T. sirtalis* 7 to 28 October.

Because snake numbers were not uniformly distributed over the days spent collecting, I performed Spearman rank correlation analysis using date, total number of snakes per date, the daily high and daily low temperatures for each date, precipitation for each date, and the river stages at Grafton and Alton for each date as independent variables to determine if any of these abiotic factors could explain the variance in snake numbers collected per day. I found no correlations between total snake numbers and any of the abiotic variables.

Because a number of species with diverse habitat requirements were included in the number for total snakes collected and because all species were not represented equally in the sample, I divided the number for total snakes into primarily terrestrial species (*Elaphe obsoleta*, *E. vulpina*, *Lampropeltis calligaster*, *L. getula*, *Pituophis melanoleucus*, *Storeria dekayi wrightorum*, *Thamnophis sirtalis*, and *T. proximus*) and primarily aquatic species (*Nerodia sipedon*, *N. erythrogaster*, *N. rhombifer*, and *Regina grahamii*) based on habitat descriptions in Smith (1961) and repeated the correlation analysis for both groups.

When grouped in this manner, no abiotic factor was significantly correlated with either the number of terrestrial snakes collected per day or with the number of aquatic snakes collected per day. The conditions during the relatively short study period (21 days) may not have varied sufficiently for effects of the abiotic factors on numbers of snakes to be apparent. Another possibility is that the species classified as primarily terrestrial or primarily aquatic differ in their responses to the abiotic variables. Consequently, I performed separate correlation analyses for the three most commonly collected species classified as primarily terrestrial (*Thamnophis sirtalis, Elaphe obsoleta*, and *E. vulpina*) and the four species classified as primarily aquatic.

No abiotic factors correlated with the numbers of *E. obsoleta* and *T. sirtalis*. However, both daily high temperature (*rho* = 0.56, p = 0.0084) and river stage at Grafton (*rho* = 0.46, p = 0.0370) correlated with number of *E. vulpina* collected each day. These correlations must be suspect considering that I collected only six specimens of the species.

In contrast to the primarily terrestrial species, the numbers collected of two of the aquatic species were correlated with one or more of the abiotic variable. The number of *N. erythrogaster* collected was correlated with daily high (*rho* = 0.44, p = 0.0457) and daily low (*rho* = 0.56, p = 0.0078) temperatures. For this species, correlation with river stage at Grafton (*rho* = 0.42, p = 0.0602) and Alton (*rho* = 0.42, p = 0.0557) was nearly significant. The number of *R. grahamii* collected was correlated with daily low temperatures (*rho* = 0.48, p = 0.0272). Both *N. sipedon* and *R. grahamii* numbers were slightly though not significantly correlated with river stage at Grafton (*rho* = 0.43, p = 0.0537 and *rho* = 0.40, p = 0.0710, respectively) and for the latter species with river stage at Alton (*rho* = 0.43, p = 0.0507).

Clearly these are preliminary results due to the short duration of the snake movement and the small sample sizes collected for each species on any one day of the study. However, the correlation between temperatures and snake activity is not unusual (see Larsen, 1989, for instance). Possible correlation of snake activity with river stage has not been reported previously. The slight correlation between aquatic snake activity and river stage could be due to actual effects on movement patterns attributable to changes in river stage. The association between snake numbers and river stage could also be due to autocorrelation because daily high temperature was correlated with daily low temperature (*rho* = 0.58, p = 0.0060). Furthermore, daily low temperature was correlated with Alton river stage (*rho* = 0.66, p = 0.0011) and with Grafton river stage (*rho* = 0.49, p = 0.0241), indicating that these abiotic variables cannot be considered independent of each other.

In order to further explore the possible relationships between the numbers of aquatic snakes and terrestrial snakes collected and daily high and low temperatures and river stage at Grafton and Alton, I performed principal component analysis (Fig. 3). The first principal component accounted for 82.08% of the variance, the second accounted for 11.32%, the third for 4.3%, and the fourth for 2.29%. Daily high and low temperatures were responsible for most of the loading of the first and second principal components with eigenvectors of 0.653455 and -0.743643 for daily high and 0.707542 and 0.644512 for daily low temperatures, respectively. Eigenvectors for river stage were uniformly low for the first two principal components being 0.233985 and 0.028268 for river stage at Grafton and 0.132783 and 0.175501 for river stage at Alton, respectively. The number of terrestrial species collected per day showed no obvious pattern. However, the clustering of the days that the largest numbers of aquatic species were collected at the positive extreme of the first principal component is consistent with the hypothesis that the aquatic snakes were more likely to be found when daily high and low temperatures were relatively high.

DISCUSSION

The number of DOR snakes/km (0.033) that I observed fell within the range of 0.0066 to 0.1754 DORs/km listed by Dodd et al. (1989, Table 1) in their summary of other studies reporting data on DOR snakes. However, such large numbers of DOR snakes is unusual for the area and may be a result of habitat changes produced by flooding.

The summer flood of 1993 (Fig. 4) covered the study area, and altered the nature of the rip rap along the road by depositing silt in the interspaces between the individual rocks that make up the rip rap. These snakes may have formerly hibernated within the rip rap and their fall movements to hibernacula went unobserved because they did not cross the road to reach suitable over- wintering sites. When flooding made these hibernacula unsuitable, the snakes crossed the road to find alternative sites.

Of the seven most commonly collected species, *N. erythrogaster, N. rhombifer, N. sipedon, R. grahamii,* and *T. sirtalis* occupy either aquatic habitats or habitats bordering water (Smith, 1961). Except for *T. sirtalis* (Fitch, 1965; Larsen, 1987), these species have not been reported to use large communal hibernacula. If these snakes were searching for hibernacula, then the observation that all but *T. sirtalis* were more or less evenly distributed along the road where it borders the river is explained. The concentration of *T. sirtalis* near km 15 may indicate a communal hibernaculum in that area. It is well known that *T. sirtalis* sometimes makes long distance (up to 17.7 km) migrations to hibernacula (Gregory and Stewart, 1975).

The assumption inherent in this scenario is that the species were resident in this area at the time of the flooding and were not displaced by the flood event. This assumption may hold for aquatic species, such as the three species of *Nerodia*. However, some species, such as *E. obsoleta, E. vulpina, P. melanoleucus*, and possibly *R. grahamii*, seem out of place in a habitat consisting of a rip rapped bank side of a large river. Smith (1961) lists primary habitat as wooded bluffs for *E. obsoleta*, black-soil prairies, pastures and fencerows for *E. vulpina*, sand prairies for *P. melanoleucus*, and lakes, river-bottom sloughs, and prairie marshes for *R. grahamii*. These species may have been dislocated

from their more usual habitats by the flooding. Unfortunately, no studies of snakes normally found in rip rapped bank sides have been published.

Few studies (Dowling, 1987; Trauth, 1990; Tucker et al., in press) describe effects of flooding on snakes. These reports seem to differ from the instance reported here. In each of the previously reported cases, unusual movements or numbers of snakes appeared while the flood event was ongoing. In the event reported here, unusual movements occurred well after the flood event itself had passed (Fig. 4). This may indicate that flooding can have long lasting effects through subtle alterations in habitat and immediate effects such as the displacement previously reported.

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Table 1. Snakes listed in order of decreasing abundance collected on Illinois Route 100, Jersey and Madison counties, Illinois between October 7 and 28, 1993.

Species number and % of total snakes collected	Mean SVL mm	Range mm	SD mm	Number of males:females
Nerodia sipedon n = 29, 25.7%	488.1	167 - 974	189.96	15 : 14
Thamnophis sirtalis n = 22, 19.5%	498.3	311 - 680	109.16	6 : 16
Elaphe obsoleta n = 13, 11.5%	873.2	497 - 1070	166.19	3 : 10
Nerodia erythrogaster n = 13, 11.5%	665.0	370 - 905	164.6	6 : 7
Regina grahamii n = 13, 11.5%	557.4	387 - 760	97.6	4 : 9
N. rhombifer n = 10, 8.8%	557.9	445 - 840	117.31	6 : 4
E. vulpina n = 6, 5.3%	822.2	555 - 1010	187.6	2 : 4
Lampropeltis calligaster n = 3, 2.7%	768.3	642 - 863	113.85	1 : 2
L. getula n = 1, 0.9%	795	------	------	1 : 0
Pituophis melanoleucus n = 1, 0.9%	1030	------	------	0 : 1
Storeria dekayi wrightorum n = 1, 0.9%	275	------	------	1 : 0
T. proximus n = 1, 0.9%	520	------	------	0 : 1

Abbreviations: n = number of specimens; SVL = snout to vent length; SD = standard deviation.

Figure 1. Location of Illinois Route 100 and place names mentioned in text with the number of snakes collected per km superimposed.

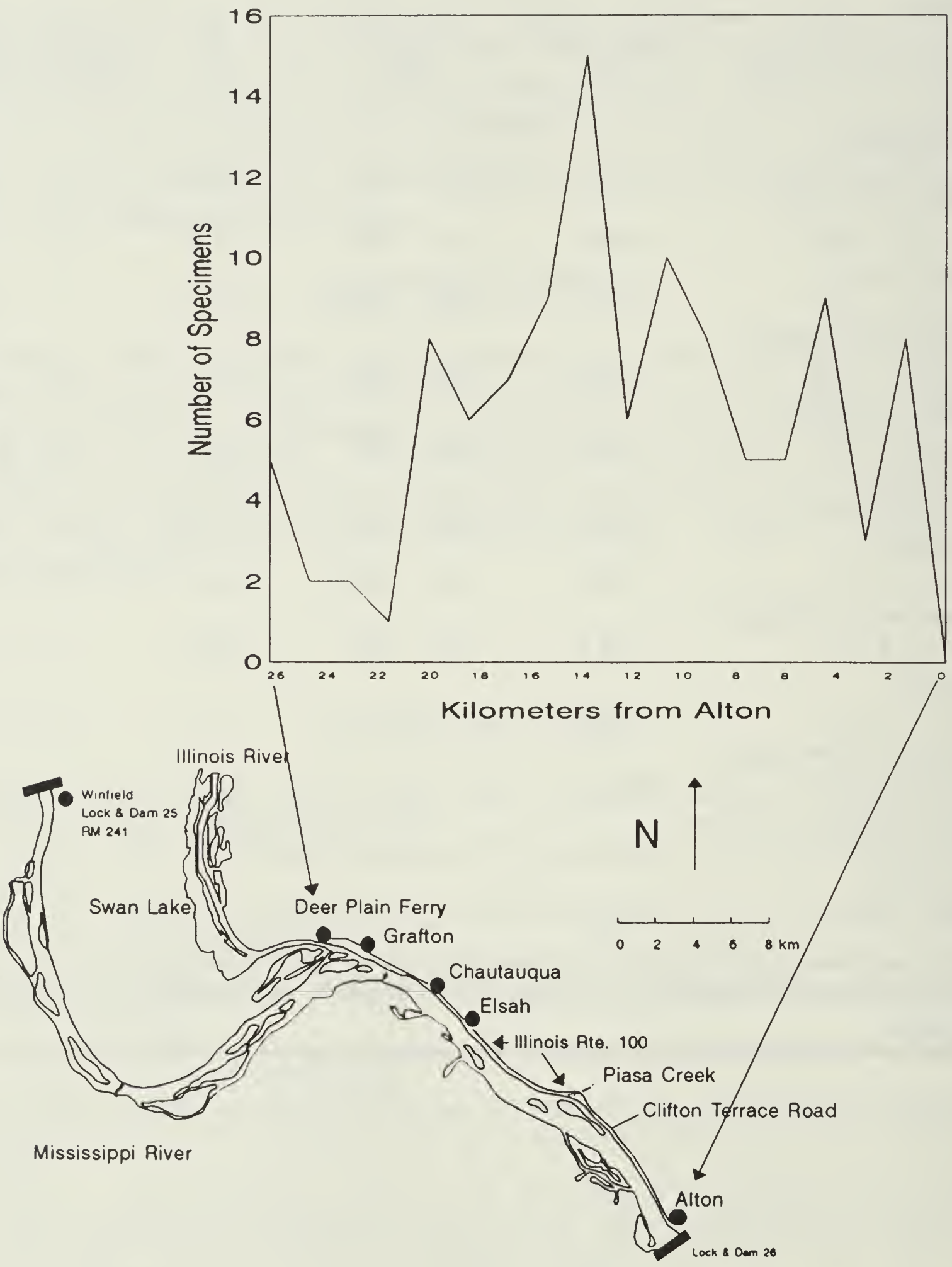


Figure 2. The number of snakes found each day between October 7 and 28 compared to daily high and low temperature (°C) and river stage (feet) at Grafton. No collections were made for October 26.

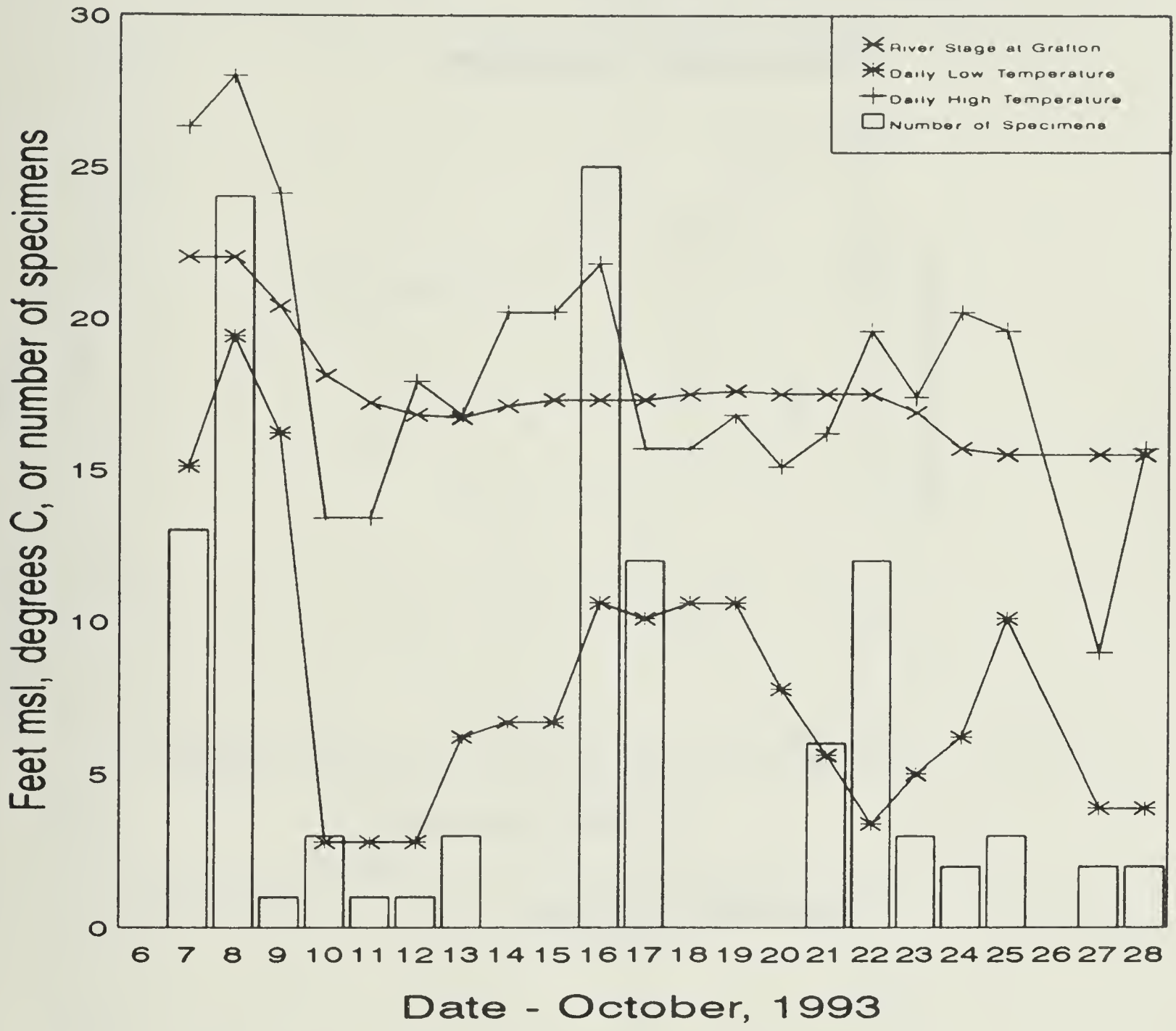


Figure 3. Results of principal component analysis including independent variables daily high and low temperature and river stage at Grafton and Alton for terrestrial and aquatic species. The numbers represent the numbers of each kind of snake collected on each day of the study.

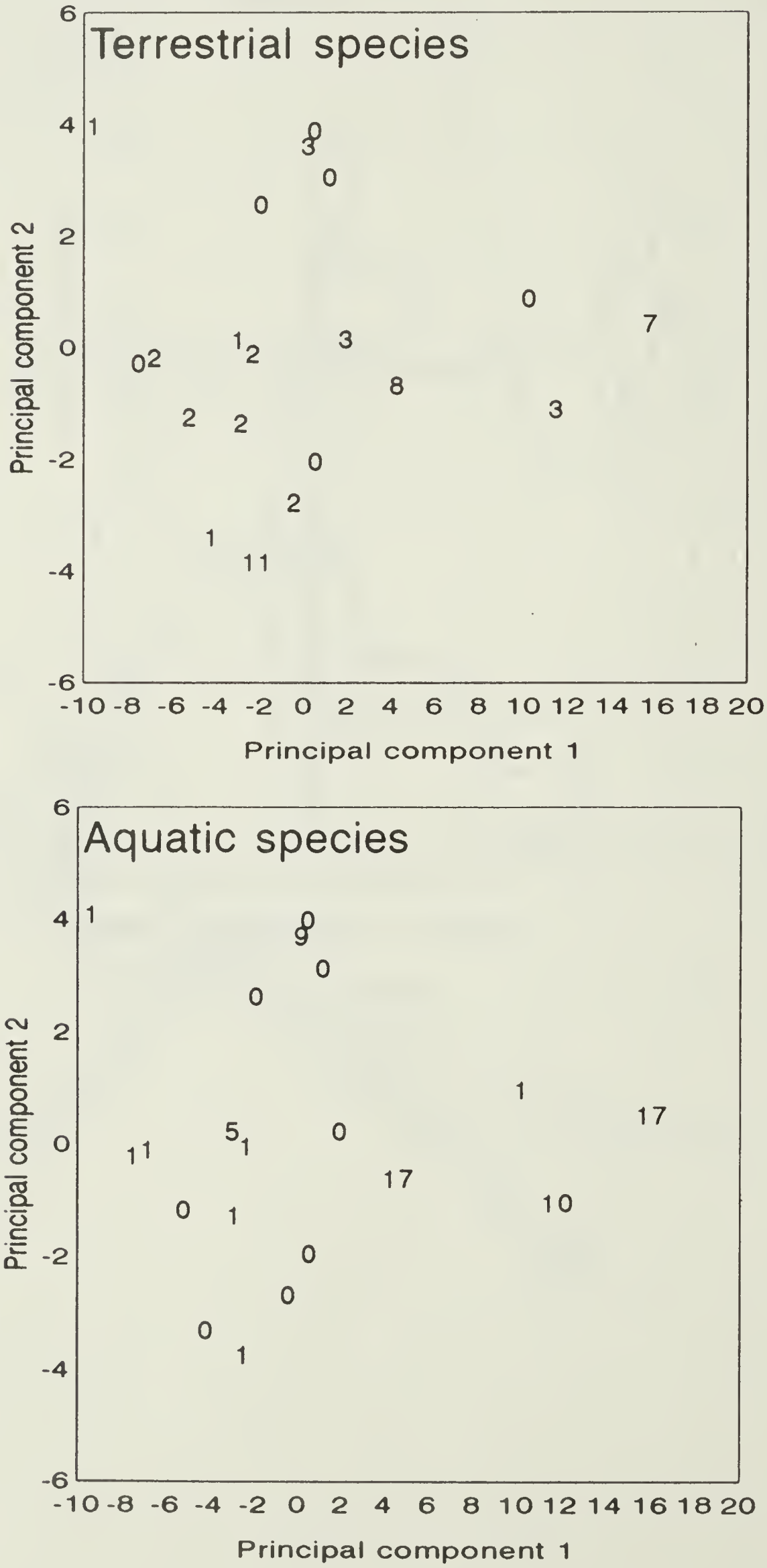
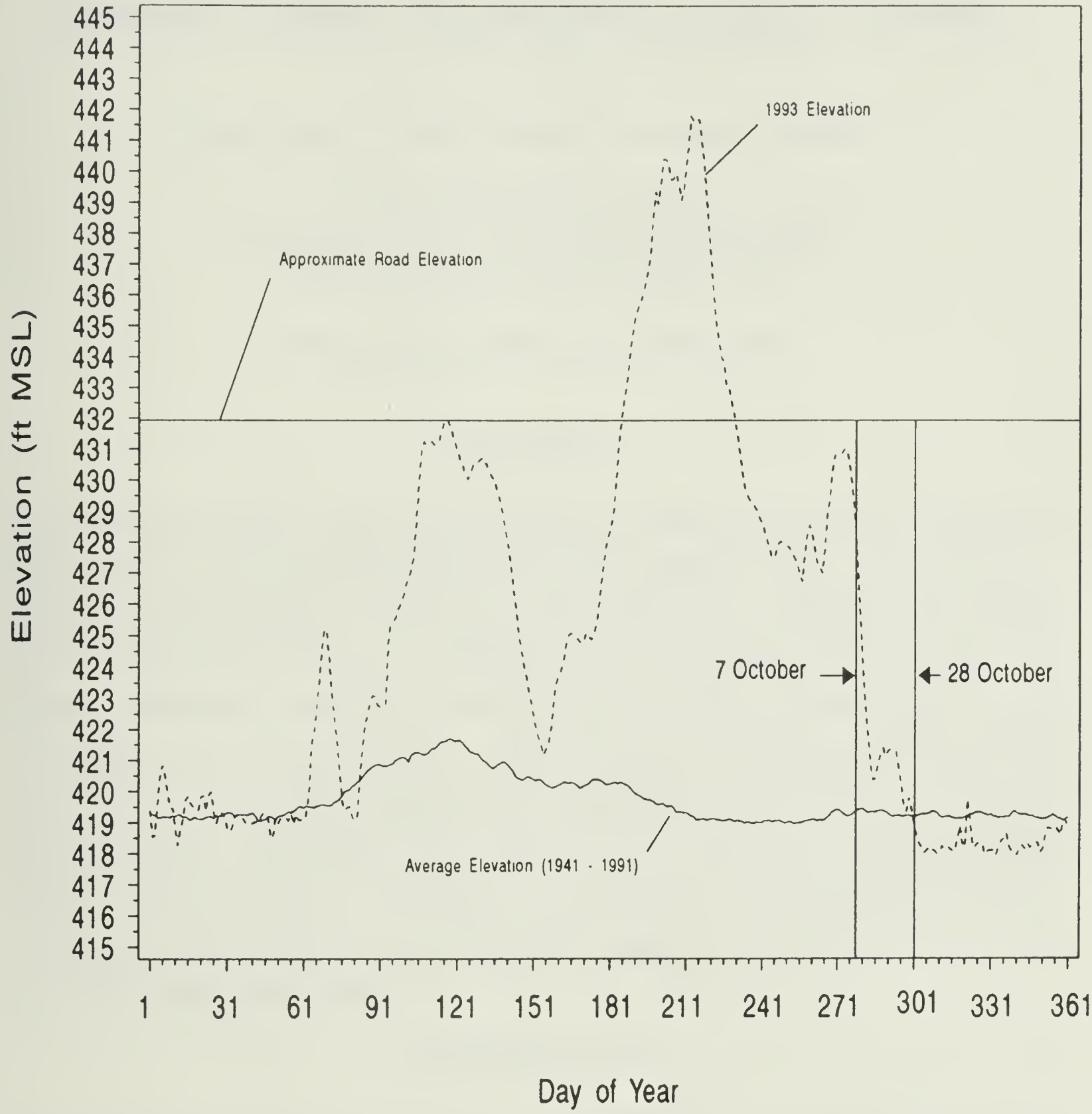


Figure 4. Hydrograph showing extent and duration of river flooding along Illinois Route 100 utilizing 432 MSL as the average elevation of the road. Period during which snakes were found on the road is shown.



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Flood-Associated Activities of Some Reptiles and Amphibians at Carlyle Lake, Fayette County, Illinois

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ABSTRACT

Heavy rains in November of 1993 caused extensive flooding of the upstream portions of Carlyle Lake, a 26,000 acre impoundment on the Kaskaskia River. Nine species of reptiles and amphibians were displaced by this flood event. Species found displaced included six species of anura, *Acris crepitans blanchardi*, *Bufo americanus*, *B. woodhousii fowleri*, *Hyla versicolor* complex, *Pseudacris triseriata*, and *Rana sphenocephala*; one species of salamander, *Ambystoma texanum*; and two species of snake, *Storeria dekayi wrightorum* and *Thamnophis sirtalis*. We found no evidence of mortality directly attributable to late fall displacement. Because mobility of the displaced animals was limited by low temperatures, predation may be an important source of mortality among displaced animals. Winter kill could result from such displacements if hibernacula are rendered useless by flooding for extended periods during more severe winter temperatures. Upstream flooding during the fall flood pulse when it is exacerbated by reservoir development and operation may be an important source of mortality for vertebrates that overwinter in flood plain forests.

INTRODUCTION

Flooding of the Mississippi River during the summer of 1993 reached record levels. This flood not only had an impact on the Mississippi River but also altered water levels in tributary streams due to flood waters backing into and flooding the tributaries. The flood also affected water management strategies adopted at reservoirs along major tributaries. Carlyle Lake, a 26,000-acre impoundment on the Kaskaskia River, is an example. Pool levels in this lake were maintained at higher levels than usual to provide flood relief downstream. Heavy rains (5 inches [12.5 cm] fell at Carlyle Lake dam between November 12 and November 14) resulted in significant flooding of the Kaskaskia River upstream of the reservoir (Fig. 1A). The flood peaked on 21 November 1993, when Carlyle Lake reached a record pool level of 455.53 feet National Vertical Geodetic Datum (NVGD). The previous Carlyle Lake pool record set 7 January 1973, which was also a major flooding year on the Mississippi River, was 455.48 feet NVGD (Pickard, 1993).

On November 21, one of us (JBH) noted many specimens of reptiles and amphibians stranded on objects floating in the flood waters in the forested area near Carlyle Lake known as the subimpoundment. The subimpoundment is not flooded when Carlyle Lake is at normal pool levels but does flood when pool levels exceed 451 feet (D. Connors, U. S. Army Corps of Engineers, pers. comm.). It is the area of the reservoir that is farthest upstream from the dam and acts to absorb flood waters to lessen economic damage from upstream flooding.

Few studies (Dowling, 1987; Trauth, 1990) describe the effects of late-season flooding on snakes. We herein report our observations on the result of late-season flooding on two species of snakes, *Storeria dekayi wrightorum* and *Thamnophis sirtalis sirtalis*. We also list the amphibians found active in the same area.

MATERIALS AND METHODS

Our studies were conducted in the subimpoundment of Carlyle Lake near the banks of the Kaskaskia River at SW$^1/_4$ Sec. 26, T5N, R1W. This location is 8 km WSW of Shobonier in Fayette County, Illinois. We collected only selected specimens of each snake species on the initial collecting trip (21 November) even though other specimens of snakes and anurans were observed. We made three subsequent collecting trips (24 and 25 November and 1 December). On these trips, we collected all reptiles and amphibians encountered because specimens with late fall/early winter collecting dates are seldom available for study.

The site where we found snakes is slightly elevated and covered an area of about 500 m^2 on either side of an unpaved road through timber. The ground cover consisted of thick stands of grasses and other forbes on the roadway and piles of deadfall branches and logs within the timber. The animals were found on tufts of grasses and on deadfall piles protruding above the water surface.

Measurements of pool level, daily high and low air temperatures, and precipitation are from the Carlyle Lake office of the U. S. Army Corps of Engineers (LMS form 89) and were measured at that office near the dam (Fig. 1B). We then converted these temperature and precipitation values to metric equivalents. Water temperatures (11°C on each trip) were recorded at the site with a LabComp SCT 100 conductivity meter on 24 and 25 November and 1 December.

We identified all reptiles and amphibians collected to species (Smith, 1961). Following fixation in 10% formalin, all specimens collected were preserved in 70% ethanol. We determined sex for the snakes through eversion of the hemipenes in males during preservation. Sex was not determined for the amphibians. We measured snout to vent length (SVL) to the nearest 1.0 mm with a metric rule for each animal collected 24 hours after preservation. Specimens are deposited in the collections of the Illinois Natural History Survey (INHS 11110-INHS 11182).

RESULTS

Water temperatures on 24 and 25 November and 1 December 11.0°C throughout the study area. We collected 94 specimens of nine species of reptiles and amphibians consisting of six anurans (*Acris crepitans blanchardi*, n = 1; *Bufo americanus*, n = 11; *B. woodhousii fowleri*, n = 4; *Hyla versicolor* complex, n = 3; *Pseudacris triseriata*, n = 6; and *Rana sphenocephala*, n = 23), one salamander (*Ambystoma texanum*, n = 2), and two snakes (*Storeria dekayi wrightorum*, n = 15 and *Thamnophis sirtalis*, n = 29). *T. sirtalis*, the most commonly collected species, made up 30.8% of the total specimens collected and 65.9% of the snakes collected. *R. sphenocephala*, the second most commonly encountered species, accounted for 24.5% of the total specimens collected and 47.9% of the anurans collected. Because not every specimen seen was collected each day and because frogs were more difficult to catch than snakes or other anurans, the relative abundance of each species in the collections does not reflect the relative abundance of these species at the site.

Sex ratios for the two snake species do not differ significantly ($p > 0.05$) from unity. For *Storeria dekayi wrightorum*, the ratio is 0.67 males : females with a chi-square of 1.6. For *Thamnophis sirtalis*, the ratio is 0.71 males : females with a chi-square of 0.86.

The broad range of SVL for both snake species suggests that both young of the year and older snakes were contained in the sample. Length frequency distributions for both species (Fig. 2) support this conclusion. We consider *S. dekayi wrightorum* with SVLs less than 180 mm to be young of the year (Noble and Clausen, 1936). Five (33.3%) of the *S. dekayi wrightorum* collected are less than 180 mm SVL whereas ten (67.7%) are larger. For *T. sirtalis*, we consider specimens less than 260 mm to be young of the year snakes (Fitch, 1965). We collected 18 *T. sirtalis* that were less than 260 mm SVL, which account for 62.1% of the total specimens of *T. sirtalis* collected. The remaining 11 specimens (37.9%) exceeded 380 mm SVL.

DISCUSSION

When we initiated this study we expected to document flood related mortality among reptiles and amphibians, particularly for the snake species. We attempted to time our collecting trips accordingly. We made the comprehensive collecting trip on 24 November to establish a baseline collection of the species that appeared to be forced into exposed situations by the flooding before a period of cold weather could set in. The trip of 25 November, which produced no specimens coincided with the start of six days (25-30 November) with daily low temperatures below freezing (Fig. 1B). We made the final trip on the first warmer day (1 December) after this cold snap in the expectation that we would find numerous casualties due to exposure to the cold nights.

Although we searched the area diligently for evidence of mortality, we found very little. We found but two dead leopard frogs and one salamander that appeared to be frost bitten but still alive. We found no dead snakes. We believe that these animals were able to avoid freezing temperatures by entering the water, which was much warmer (11°C) than the night air. Therefore we conclude that displacement by late fall/early winter flooding did not directly cause excessive mortality due to exposure because freezing temperatures

were easily avoided by most animals. This conclusion is consistent with reports of winter kills such as for turtles (Christiansen and Bickham, 1989), which occur where freezing conditions cannot be escaped.

Even though this flood event may not have directly caused mortality, the affected animals were likely exposed to increased risk of predation. The sluggish movements of the snakes and the relative ease with which we were able to catch leopard frogs suggests this possibility. The snakes made no effort to escape even though they were completely exposed to view. When touched, they moved slowly and, in some cases, merely thrashed about rather than attempting to hide.

We also observed predators or their scats in the relatively restricted study area. On one occasion, four Great Blue Herons (*Ardea herodias*) noisily flew from the study area as we approached. We also observed numerous scats of the raccoon (*Procyon lotor*) at the study area on each of our trips. Both of these animals are known to prey upon snakes (see Fitch, 1965, for instance). One of the dead leopard frogs had been partially eaten further suggesting that predation was a factor at this site.

Since at least *T. sirtalis* is known to be able to hibernate submerged (Carpenter, 1953; Costanzo, 1985, 1986, 1989a, and 1989b; Ultsch, 1989) in water and possibly with less mortality (Costanzo, 1989b) than individuals hibernating exposed to air, we wonder why the snakes left their hibernacula at all. We suspect that the relatively high water temperature (11°C) caused the snakes to abandon their hibernacula. Costanzo (1989b) found that at 12°C submerged hibernating *T. sirtalis* consumed lipid and protein reserves at much higher rates than they did at lower temperatures. However, no data exists on whether *T. sirtalis* or *S. d. wrightorum* hibernates submerged in Illinois.

We believe that the snakes in our example were displaced from one or at most a few hibernacula because the area in which we found snakes was only a small part of the area that we covered looking for snakes. In many cases, several snakes of the same species were found immediately adjacent to each other. This is consistent with previous reports on use of communal hibernacula in both *T. sirtalis* and *S. dekayi* (MacMillan, 1988; Carpenter, 1953; Macartney et al., 1989; Bailey, 1948; Noble and Clausen, 1936) and scent trailing of conspecifics by both species (Noble and Clausen, 1936; Larsen, 1987; Costanzo, 1989c).

While we cannot determine if these snakes were all using a single hibernaculum, it is noteworthy that young of the year snakes and older snakes were found together. Previous authors (Aleksiuk and Gregory, 1974; Gregory, 1974 and 1977; Gregory and Stewart, 1975; Larsen and Gregory, 1989; Larsen and Hare, 1992) working with migratory northern populations of *T. sirtalis* report that young of the year and juvenile snakes are not found hibernating with adults (but see MacMillan, 1988, for an exception). They suggested that young of the year and juvenile snakes were unable to make the long distance migrations necessary to move from feeding ranges to hibernacula. We suspect that this is not applicable to the situation that we encountered because the hibernaculum or hibernacula are located in habitat suitable for summer occupation by garter snakes. Consequently, the snakes using the hibernaculum or hibernacula probably did not have to make a long range migration to reach it.

Our conclusion that flooding, while possibly not the proximal cause of mortality, may increase mortality from other causes, and is quite similar to the case reported by Trauth (1990) for *Nerodia cyclopion* in Arkansas. In Trauth's (1990) study flooding forced the snakes from hibernacula onto roads where they were killed. Tucker (in press) found large numbers of snakes killed on a road in Jersey and Madison Counties apparently as a result of habitat alterations due to the summer flood of 1993 along the Mississippi River.

There are other similarities between our observations and those reported from Arkansas by Trauth (1990) and from Illinois by Tucker (in press). In Trauth's example, the area that flooded was also upstream of a lake. Heavy November rainfall was the proximal cause of flooding in his example as it was in ours. Forced from their hibernacula, the Arkansas snakes became vulnerable to predation due to low air temperatures that prevented their escape. In Tucker's (in press) example, snakes had to cross a road to reach hibernacula uneffected by summer flooding. Similarly, we suspect that the Carlyle Lake flooding rendered hibernacula useless for at least some period of time. While predation may be the primary proximal threat facing the snakes that we studied, winter kill of poorly protected animals may become important if hibernacula cannot be reoccupied before temperatures fall well below freezing.

Flooding in flood plain forests is a natural event and flood pulses in the spring and fall frequently occur in natural systems (J. Nelson, pers. comm.). However, we wonder if the development of reservoirs such as Carlyle Lake might not exacerbate the situation and make the impact more detrimental to reptiles and amphibians than would be the case if the lake were not there. Although the species that we observed are common snakes in Illinois (Smith, 1961), other less common species are known from Fayette County including *Clonophis kirtlandii* (Holman and Arai, 1962) and *Sisturus catenatus* (Smith, 1961), species that are now listed as threatened in Illinois (Herkert, 1993). Both species occur in the vicinity of Carlyle Lake (S. Ballard, Illinois Dept. Conservation, pers. comm.) and occupy wetland habitats (Smith, 1961).

Two reports (ours and Trauth's, 1990) document impact of late season flooding upstream from lakes or impoundments. Managers of such lakes and particularly those that effect habitats of endangered or threatened species should strive to mimic summer low water levels. Return to a more natural hydrology would reduce the duration and magnitude of fall floods by lowering impoundment water levels prior to fall flood pulses. Our study is consistent with that of Kushlan and Jacobsen (1990) who reviewed a number of studies showing that departures from natural hydrological patterns are detrimental for organisms ranging from the apple snail (*Pomacea paludosa*) to the alligator (*Alligator mississippiensis*) in the southern Everglades of Florida.

Finally, we believe that our study and Trauth's (1990) indicate that late season flooding can provide the herpetologist with an opportunity to sample flood plain reptiles and amphibians when the proper conditions exist. Herpetologists should make every effort to enter and survey flooded areas if the temperatures are not significantly below freezing at night and if the air temperature during daylight hours is warmer than the flood water temperature.

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Figure 1. (A) Hydrology for the month of November and 1 December showing extent and duration of subimpoundment flooding at Carlyle Lake, Fayette County, Illinois. (B) Daily high and low air temperatures (C) and precipitation (cm) for the same period.

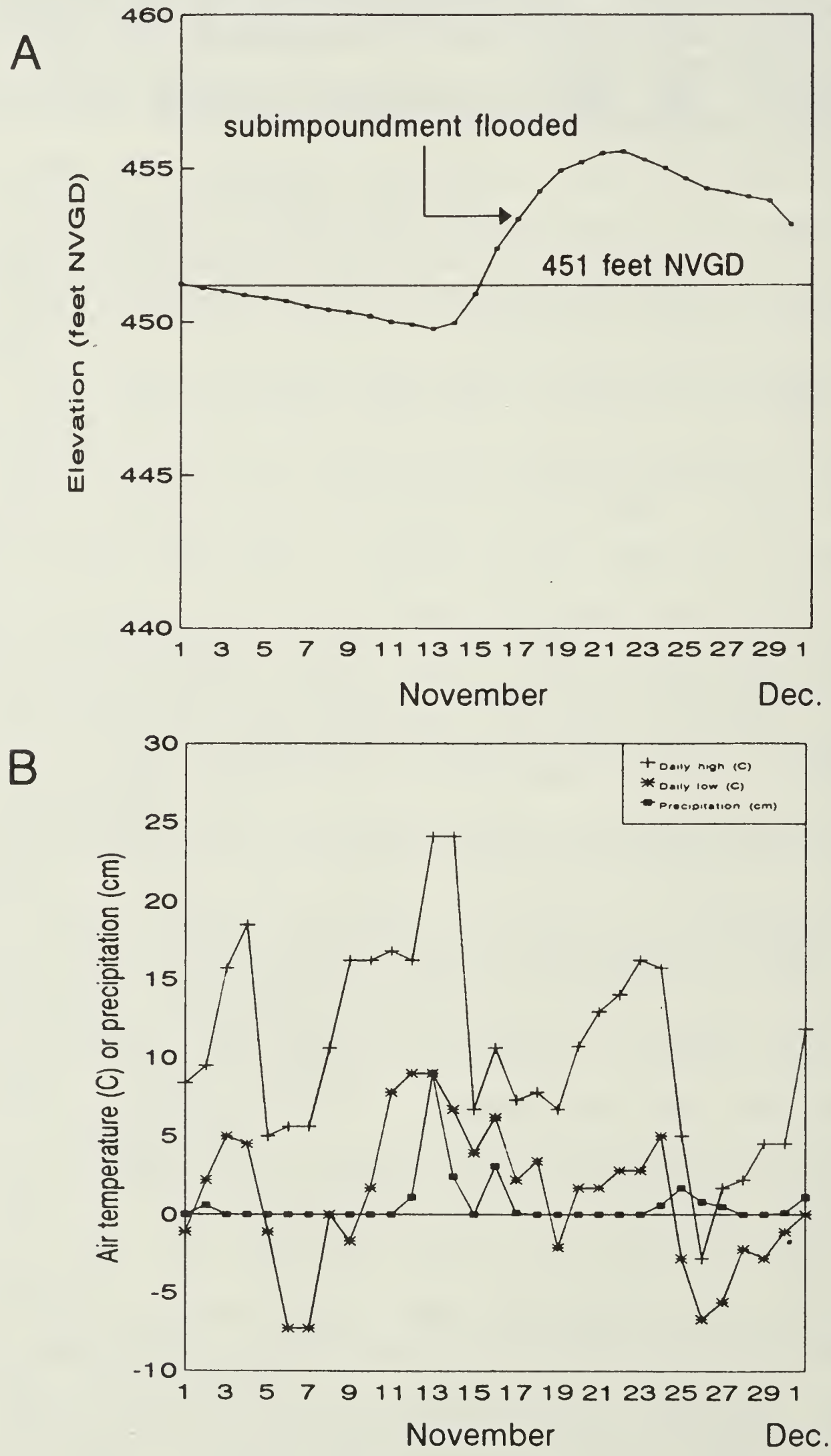
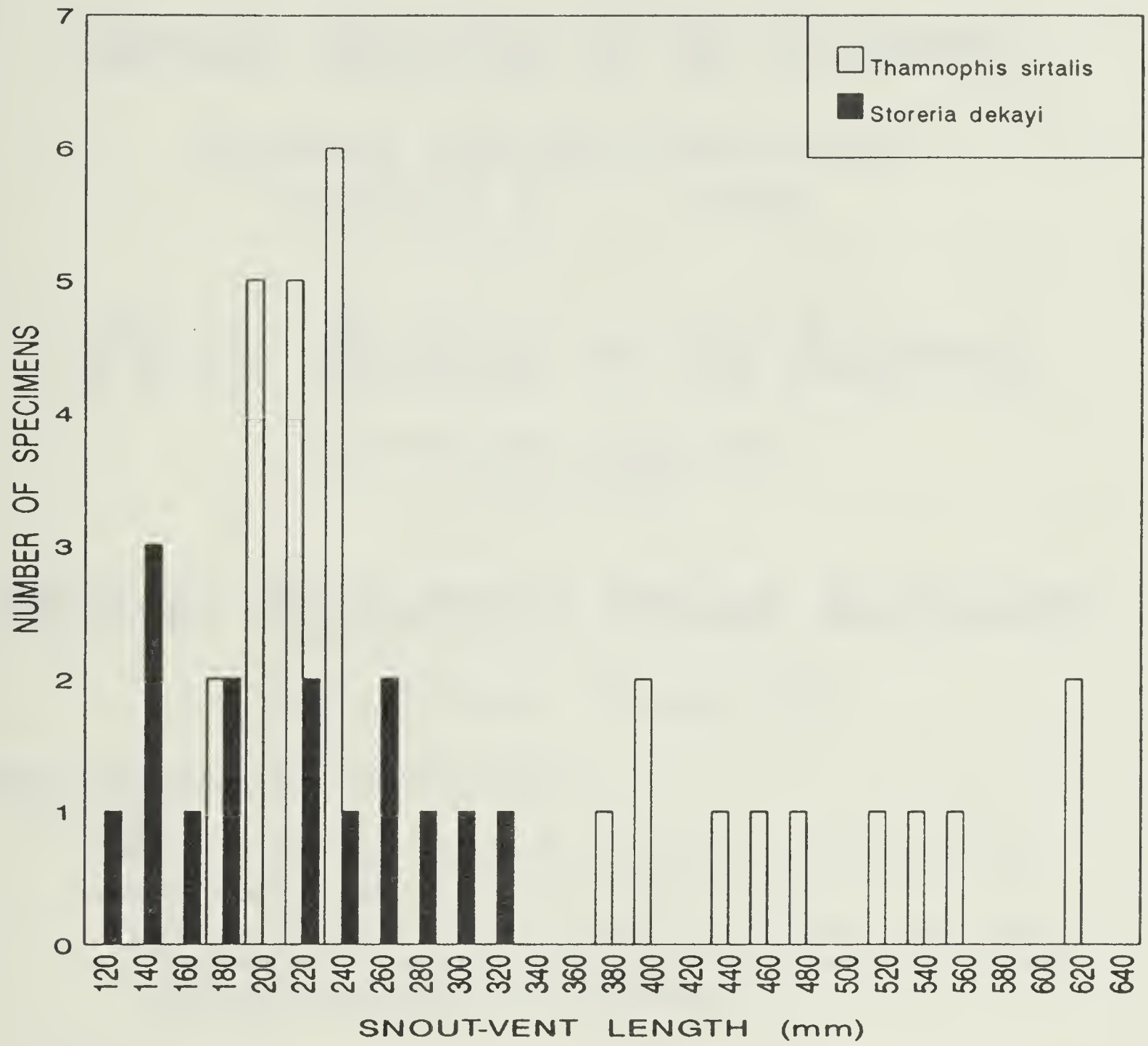


Figure 2. Length frequency distribution of specimens of two snakes collected at Carlyle Lake.



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Eastern Illinois University
October 6 - 7, 1995

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AUGUSTANA COLLEGE
October 1996

Student Competition Award Recipients

Annual Meeting - October 1994

Botany Division - Best Student Paper

1st Place

Robert L. Kovacs, Department of Plant Biology, Southern Illinois University - Carbondale

Kovacs, Robert L., and Walter J. Sundberg. Preliminary report on the elucidation of the host range of *Syzygites megalocarpus* (Zygomycetes, Mucorales, Mucoraceae) in the United States

2nd Place - Tie

Cheryl Cloninger, Department of Biology, Southern Illinois University - Edwardsville

Cloninger, Cheryl, Marion Smith, and Kurt Schulz. Stomatal conductance and fluorescence of *Impatiens pallida* in response to high light.

Robin McCall, Department of Plant Biology, Southern Illinois University - Carbondale

McCall, Robin K., and David J. Gibson. The regenerating ability of a threatened shale glade barrens in southern Illinois.

Health Science Division - Best Student Presentation

1st Place

D. Jeremy Ufert, Department of Biological Sciences, Southern Illinois University - Edwardsville

Cytokine effects on murine immune response to the zygomycetous mold *Circinella*.

Student Research Grant Recipients

October 1994

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Illinois State University

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7. In the text, references must be quoted by the author's name and date, e.g., (Smith, 1960). Footnotes are to be avoided.
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Transactions of the Illinois State Academy of Science
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Erratum

Listed below is a correction to a manuscript which was previously published in the Transactions of the Illinois State Academy of Science. The correction is printed on the following un-numbered page for easy insertion into the original manuscript.

The Table of Contents for Volume 88, 1 and 2 incorrectly listed the Chemistry section papers. The Contents listed a paper by Nelson, et al beginning on page 21. The paper which actually appears was by Reynolds, et al.

Transactions of the Illinois State Academy of Science
Volume 88 (1995)

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Transactions of the Illinois State Academy of Science
(1995), Volume 88, 3 and 4, pp. 89-90

In Memorium

John William Reeves

October 15, 1923 - March 19, 1995

John William Reeves, 30 Shorewood Drive, Macomb, Illinois, passed away Sunday, March 19, 1995 at the age of 71. John is survived by his wife of 45 years, "Billie", the former Willa Steelman, whom he married in Moscow, Idaho on June 4, 1949. He is also survived by three sons, John Thomas of Edwardsville, Illinois, Michael William of Burns, Oregon, and Robert Joe of Cobden, Illinois; one daughter, Ruth Ann Hoak of Makanda, Illinois; seven grandchildren; and one sister, Betty Bacus of Sarasota, Florida.

John served in the Army in Europe during World War II where he received the Purple Heart and was a P.O.W. in Germany after his capture during the Battle of the Bulge.

John earned his B.S. and M.S. degrees in Forestry at the University of Idaho and worked for the Chevron Chemical Company for many years in the orchard industry. In 1967 he left Chevron to become land manager for Southern Illinois University, Carbondale's "Touch of Nature" outdoor lab. While at SIU, John taught in the Forestry Department and completed work on his Ph.D. in Botany.

While in southern Illinois, John was a member of the First Presbyterian Church in Cobden where he served as deacon and a Sunday school teacher. He was a member of the Anna V.F.W.

In 1976 John joined the staff at Western Illinois University with a dual appointment in the Recreation, Parks, and Tourism Department and the Agriculture Department, later becoming full-time in Agriculture. He retired in June of 1993 as professor of urban forestry in the Agriculture Department at WIU after 17 years of service. In addition to the courses he taught, John directed youth conservation workshops for several summers and served on a number of university committees.

While at WIU, John developed and began teaching the first urban forestry program in Illinois. Over the years he mentored many fine students who are now making contributions today in the fields of urban forestry and arboriculture. John's dedication to the field of urban forestry was matched only by the love that he had for his students. His greatest satisfaction came from sharing his knowledge of trees and conservation with students and helping them grow professionally.

John also provided technical assistance in urban forestry to a number of communities in the region. He dedicated many long hours of volunteer service as technical advisor to Greener Macomb in working to develop a community forestry program for the City of Macomb. With John's guidance and expertise, Macomb was able to adopt its first comprehensive tree ordinance, plant many new street trees, begin

better caring for its existing trees, and earn the national recognition of Tree City, USA for the last three consecutive years.

John was active in the Illinois Academy of Science which he joined in 1977. He served the Academy as Agriculture Section Chair for 6 years, 2nd Vice President in 1983, President-elect in 1984-5, and a 2 year term as President from 1985 to 1987. More recently, John was elected as a Fellow of the Academy. As a scientist, John was the author of many publication in professional journals. Perhaps his most noteworthy, was as co-author of a paper presenting a mathematical formula for establishing an ecological dollar value for individual trees without reference to non-ecological amenity values. This is a method which has been and is still currently being used for appraisal of individual trees that have little or no ornamental value.

John was a certified arborist and long time member of both the International Society of Arboriculture and the Illinois Arborist Association. In December of 1993, John received the Association's Award of merit, its highest honor given in recognition of outstanding service in advancing the principles, ideals, and practices of arboriculture. He was scheduled to receive the Daughters of the American Revolution National Conservation Award on Friday, March 24th, 1995.

John's strong conservation values, sense of fairness, and zest for life won the hearts and respect of those who were fortunate enough to have shared a part of their lives with him. His presence will be missed.

Memorial services were held Tuesday, March 21, 1995 at the First Presbyterian Church in Macomb, Illinois. Additional services were held at the First Presbyterian Church in Cobden, Illinois Wednesday, March 22, 1995. Cremation rites were accorded with burial of ashes at a memorial tree in the Cobden Cemetery. Memorials may be made to either the John "Doc" Reeves Urban Forestry Scholarship in care of the WIU Foundation Office, Greener Macomb, or the First Presbyterian Church.

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Growth of Garlic Mustard (*Alliaria petiolata*) in Native Soils of Different Acidity

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ABSTRACT

Garlic mustard (*Alliaria petiolata*) is a naturalized, invasive plant in North America. Its current distribution in Illinois is primarily limited to the northern two-thirds of the state. Decreased colonization by this exotic species in the southern one-third of Illinois may be related to the lower soil pH conditions found there as compared with central and northern portions of the state. The pH of soil samples taken from areas supporting populations of garlic mustard tended to be less acidic than soils obtained from southern Illinois sites. Transplanted seedlings from a population of garlic mustard in McLean County, Illinois, were grown in the southern Illinois soils and soil from their place of origin. Their growth was compared by the number of surviving plants and on a total dry weight basis. A significant positive correlation between increasing plant weight and pH suggests that lower pH conditions in the southern portion of Illinois may be a factor limiting the spread of garlic mustard in this area.

INTRODUCTION

Knowledge of soil pH is fundamental to the understanding of soil systems. Inferences regarding soil nutrient status, stage of soil genetic development, and potential toxicity of environmental contaminants, among others, can be made based upon a knowledge of soil pH (Moore and Loeppert 1987). Zollinger and Kells (1991) state that various weed species have been shown to exhibit differential growth and reproductive responses to soil pH. The effect of soil pH on growth and reproductive parameters may act to limit the geographic distribution of pH-sensitive species, thus making it possible to predict future distributional changes of such species based partially on soil pH data. Field observations of garlic mustard (*Alliaria petiolata*), a naturalized, invasive biennial species in North America, indicated that by 1991 it had not invaded most of the southern third of Illinois, where the soils tend to be more acidic than elsewhere in the state (Schwegman 1988, Nuzzo 1991, Nuzzo 1993). In the British Isles, garlic mustard distribution is reported to be associated with calcareous soils, with populations most commonly occurring in hedgerows, shady waysides, and as ground cover in deciduous woods on base-rich soils (Clapham et al. 1962, Cavers et al. 1979). Grime et al. (1988) reviewed the distribution of garlic mustard in Britain and North America and reported that the species was absent from highly acidic soils. To test the hypothesis that soil pH might play a role in limiting

the plant's distribution in Illinois, the soil pH was measured at sites with and without populations of garlic mustard. Also, the growth of seedlings transplanted from Ewing Park, Bloomington, Illinois was compared under growth chamber conditions, in soil collected from five locations from southern Illinois, and Ewing Park. None of the southern Illinois sites supported garlic mustard populations at the time the soil samples were collected.

METHODS

The southern Illinois soils were collected on 16-17 January 1991 from Fayette, Marion, Pope, and Johnson Counties. They were transported to Illinois State University, placed in plastic bags and stored at a temperature of 0-2° C in a walk-in cold room until March 21. Then they were placed in a growth chamber and air dried. Soil was collected from Ewing Park on March 29. All of the collected soils were allowed to air dry until April 2. Following air drying, the soils were broken into smaller aggregates that were less than one cm in diameter. The soils were mixed with pearlite (1:1 by volume) and for each of the six soils, seven 10 cm diameter pots were filled with the mixture.

A block of soil approximately 20 cm x 20 cm x 15 cm containing several hundred garlic mustard seedlings was collected at Ewing Park on the same day as the soil. Seedlings were placed in a growth chamber set for a 14/10 hour day/night cycle with a day/night temperature of 24/22° C and watered daily with deionized water.

On April 2, a single seedling was planted in each of the pots. Seedlings were watered and the pots were placed in trays. About one cm of water was placed in the bottom of each tray to ensure soil hydration. To reduce stress on transplanted seedlings, one-half of the lights in the growth chamber were turned off for the first two days after planting. The plants were grown until June 27 under growth chamber conditions described above. At the end of the growth period, the plants (aerial and subsurface portions) were harvested, oven dried at 80° C for 48 hours and weighed. The number of surviving plants for each soil type was recorded.

The pH of the air dried soils at the beginning of the growth experiment and of the soil-pearlite mixture at the termination of the experiment was measured. In addition, the pH of soil samples collected from sites in northern and central Illinois where garlic mustard was abundant were also measured. These sites were chosen to provide comparisons of soil pH conditions in northern and central regions of the state, where garlic mustard can be readily found, to those from the southern counties where garlic mustard is limited in range. Soil samples from these sites were air dried in a growth chamber, then a 25 g sample of each was combined with 10 ml deionized water just before testing. Soil pH was measured with a Nester Pocket pH meter with an accuracy of ± 0.1 pH units. The accuracy of the meter was calibrated before each use with pH buffers 4.0 and 7.0.

RESULTS AND DISCUSSION

Garlic mustard was found to grow in soils displaying a wide range in soil pH from a low of 5.0 at Lloyds Woods in Lake County to a pH that was slightly above neutral 7.2 at Ewing Park (Table 1). The soils from southern Illinois were generally more acidic than those in which garlic mustard was growing. All of the soils from southern Illinois used in the growth experiment had higher soil pH at the end of the experiment than they did at the beginning, as did the soil from Ewing Park (Table 2).

The number of plants surviving to the end of the experiment varied from 2 to 6 for the various soils. However, chi-square analysis indicated that there were no significant differences ($p < 0.05$) in the proportion of plants surviving in the various soils. It is of interest that the Ewing Park soil, which is the soil type from which the seedlings used in the experiment were collected, had the smallest number of plants surviving. In spite of the growth of some plants in all of the southern Illinois soils, there was a significant positive correlation (Pearson Product-Moment Correlation, r) between the average plant weight and soil pH for the five southern Illinois soils (Figure 1). These results indicate that garlic mustard is capable of growing in soils from southern Illinois but that the success of the plant, as measured by plant dry weight, increases as the soil becomes less acidic. These findings are in congruence with those of Zollinger and Kells (1991) who reported that dry weight production of perennial sowthistle (*Sonchus arvensis* L.) at pH 5.2 was 29 and 31% lower than at pH 6.2 and 7.2, respectively. It should be noted that the plants are not responding directly to the concentration of hydrogen ions in the soil. Soil pH is usually reflective of the availability of nutrient ions in the soil (especially ionic forms of bases Ca, Mg, and K). According to Schubert et al. (1990), in addition to the negative effects of low soil pH itself, increased concentrations of ionic Al and Mn and deficiencies of phosphate, sulfate, and ionic Ca and Mg may lead to decreased plant growth in acidic soils. Studies of other species in the Brassicaceae have shown soil pH to affect Ca uptake in root tissue (Myers and Campbell 1985). The decrease in plant growth associated with increased acidity is probably the result of the more acidic soil having lower availability of inorganic nutrients than the less acidic soils. Reduced growth of garlic mustard in acid soils may limit its invasion of the southern one-third of Illinois.

ACKNOWLEDGMENTS

Funding for this project was provided by the Illinois Department of Conservation. We thank J. Schwegman, Natural Heritage Division of IDOC, for suggesting the study and collecting soil samples from southern Illinois.

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Table 1. The pH of soils from various locations in Illinois supporting populations of garlic mustard.

Location	County	Soil pH
Wright's Woods	Lake	5.9
Ryerson Conservation Area	Lake	5.3
Lloyds Woods	Lake	5.0
Fermilab Site 1	Kane	7.1
Fermilab Site 2	Kane	7.2
Ewing Park	McLean	6.1
Little Mackinaw Wildlife Park	Tazewell	7.2
Indian Creek Woods	Tazewell	7.0
Mettler Woods	DeWitt	5.9
Sand Prairie Scrub Oak NP (Site 1)	Mason	6.4
Sand Prairie Scrub Oak NP (Site 2)	Mason	6.3

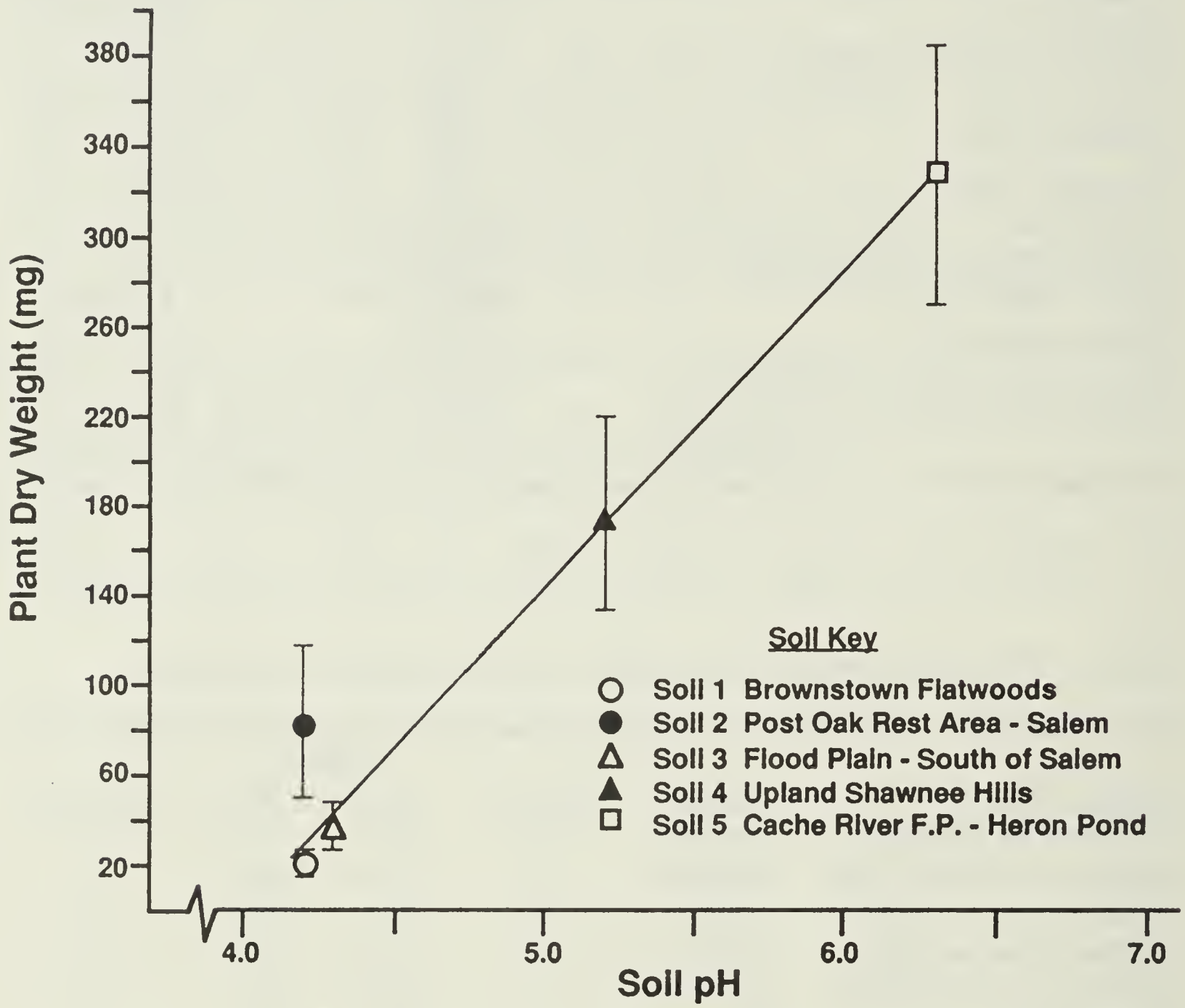
Table 2. Initial and final pH of soils used in growth comparison experiment.

			Soil pH[1]		
Habitat Type	County	Soil No.[a]	Intial	Final	No. Plants[1]
Brownstown Flatwoods	Fayette	1	4.2	4.7	4
Southern Till Plain Slope	Marion	2	4.2	4.3	6
Small stream floodplain	Marion	3	6.3	6.8	5
Upland Shawnee Hills	Pope	4	4.3	4.7	6
Cache River Floodplain	Johnson	5	5.2	5.3	6
Ewing Park	McLean	–	6.1	6.3	2

[a] Soil number in Table 2 corresponds with number in Figure 1

[1] Number of surviving plants out of seven planted per soil at the beginning of the study

Figure 1. Growth of garlic mustard in southern Illinois soils. Soil numbers in figure correspond to numbers presented in Table 2.
(Regression Equation - $Y = 0.1313X + 0.5281$; $r = 0.98$; $p < 0.001$)



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Factors Affecting Nitrogen Fixation in *Azolla caroliniana*

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ABSTRACT

The effects of environmental variables on nitrogen fixation and growth of *Azolla caroliniana* were studied. Nitrogenase activity was highest at ~25°C. Nitrogenase activity was highest at photosynthetic photon flux densities of 400-1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and decreased sharply at lower levels. *Azolla* showed great sensitivity to drying in that nitrogenase activity was approximately halved as moisture concentration decreased from 95% to 87% of total fresh plant mass. A strong diurnal pattern of nitrogenase activity was detected; this pattern was not due to an endogenous rhythm. High plant density decreased specific nitrogenase activity per unit plant mass and per unit area; the optimal plant density for nitrogen fixation on an area basis is approximately 50-100 $g_{dry} \cdot m^{-2}$. Two or 10.0 mg NH_4-$N \cdot l^{-1}$ decreased nitrogenase activity; 10.0 mg NO_3-$N \cdot l^{-1}$ decreased nitrogenase activity while 10.0 mg urea-$N \cdot l^{-1}$ was associated with an increase in nitrogenase activity. Ten mg NH_4-$N \cdot l^{-1}$ caused a decline in Azolla growth; 10.0 mg NO_3-$N \cdot l^{-1}$ resulted in an increased growth rate.

INTRODUCTION

The genus *Azolla* comprises seven species of symbiotic nitrogen-fixing aquatic ferns. *Azolla caroliniana* is found in rivers and cypress swamps of southern Illinois. The symbiosis consists of an association between the fern *Azolla* and the cyanobacterium (blue-green alga) *Anabaena azollae*, which inhabits cavities in the leaves of the fern (Lin and Watanabe 1988, Hill 1975). The cyanobacterium carries out the process of nitrogen fixation, i.e., the enzymatic reduction of atmospheric dinitrogen to ammonia (Oes 1913, Olson 1970, Venkataraman 1962). *Azolla* is economically important as a natural source of nitrogen fertilizer for agriculture in many areas of the world where industrially manufactured nitrogen fertilizers are expensive or unavailable (Lumpkin and Plucknett 1982). *Azolla* has the potential to become important in the industrialized countries for nitrogen fertilization and soil organic matter management. Its role in the nitrogen economy of natural wetlands in North America has not been established. Physiologically, *Azolla* species and strains differ in their responses to environmental variables (Vu et al. 1986, Subudhi and Watanabe 1981). The purpose of this study was to determine the effects of temperature, photosynthetic photon flux density (PPFD), time of day, moisture, plant density, and combined nitrogen on nitrogen fixation by *Azolla caroliniana* of southern Illinois. This information could be useful in the cultivation of *Azolla* for use in Illinois agriculture and in understanding

the impacts of high nitrogen levels from pollution and other environmental factors on nitrogen fixation by this plant in wetlands.

METHODS AND MATERIALS

Azolla caroliniana in southern Illinois inhabits ponds, cypress swamps and slowly-flowing rivers. The *Azolla* studied in these experiments was collected at Cache River, Pulaski County, Illinois (37°03'30"N, 89°03'30"W) from a cypress and tupelo swamp. A single clone of *Azolla* derived from one frond was propagated vegetatively in a greenhouse on the N-free medium (pH 5.2) described in Table 1.

Nitrogen fixation by *Azolla* was estimated by the acetylene reduction assay (Stewart et al. 1967, Cornaby and Waide 1973). This assay exposes the symbiont of nitrogen fixing plants or plant parts to 10% acetylene; the nitrogenase enzyme complex breaks the triple bond of acetylene, producing ethylene, just as it ordinarily breaks the triple bond of dinitrogen as the first step in producing ammonia. Experimental plants were placed in 240 ml jars fitted with airtight lids and rubber septa. Except in the case of the moisture experiment, 40 ml of the culture medium was placed in the assay vessel along with the plants. Ten percent of the air was withdrawn by syringe from each vessel and replaced with an equal volume of acetylene. Incubation was conducted for 1.00 h; then a gas sample was withdrawn, 1.0 ml for immediate analysis or 10.0 ml for storage in vaccuum tubes for later analysis. Samples were analyzed for ethylene content by gas chromatography using a flame ionization detector.

Temperature Experiment

Three to five fronds of *Azolla caroliniana* from greenhouse stock were placed in each of five 240 ml jars open to the atmosphere in a growth chamber (Fisher Scientific #626, .75 m^3) 22 h prior to measurements on each of 10 consecutive days. Photosynthetically active radiation was provided on a 0400-2000 h schedule by a fluorescent lamp providing a photosynthetic photon flux density (PPFD) of ~125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at plant height. The ten temperature treatments consisted of a series ranging from 0°C to 45°C in 5C° increments. The acetylene reduction assays were conducted at noon. Mean values and standard errors were calculated to determine magnitude of effect and statistically significant differences where error bars do not overlap.

Photosynthetic Photon Flux Density (PPFD) Experiment

Seven shade treatments (100, 67, 43, 27, 10, 3.0 and 1.7% full solar irradiance) were imposed using shadecloth in a greenhouse and 3-5 *Azolla* fronds per cup in 100 ml cups (4 replications per treatment) were placed under the shadecloth 24 h prior to measurements. Shading decreased the PPFD measured with a quantum meter (Li-Cor, Lincoln NE) allowing us to measure the effects of reduced solar irradiance on nitrogenase activity. The acetylene reduction assay for nitrogenase (nitrogen fixation) activity was conducted at midday on a sunny, cloudless day under ambient greenhouse conditions with PPFD values of 1500 ± 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Moisture Experiment

In the laboratory 21 different *Azolla* fronds collected at midday from full light conditions in a greenhouse were dried to various degrees by placing the plants on absorbent paper towels for periods ranging from 1 to 20 minutes. The acetylene reduction assay was conducted immediately after drying at 25°C under fluorescent lamps providing a PPFD of 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in the laboratory. Moisture content was determined by comparing fresh mass (immediately after assay) to oven-dry (70°C) mass by the equation:

$$H_2O \text{ content } (\%) = ((mass_{fresh} - mass_{dry}) \div mass_{fresh}) \text{ X } 100 \qquad \text{(Equation 1)}$$

The best fit of a regression line was determined by comparing r^2 values for linear and curvilinear regression equations, and the equation yielding the highest r^2 value was plotted together with the data points.

Diurnal Nitrogenase Activity Experiment

The acetylene reduction assay was conducted on five sets of *Azolla* plants every three h from 0000 to 2100 in the greenhouse under natural illumination only on a sunny, cloudless day, photoperiod ~14 h, under the temperature ranges described previously. Maximum PPFD was 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and occured at noon. The purposes of this study were to confirm that that midday sample on cloudless days had the highest daily nitrogenase activity values and to confirm the probability that nitrogenase activity is closely linked with photosynthesis. Also, four other experiments were conducted to determine whether the diurnal pattern depends on an endogenous circadian rhythm of nitrogenase. The plants were subjected to various treatments and assayed for nitrogenase activity at 3, 4, or 12 (day-night) intervals. Treatments were 1) complete darkness for 3 d, assay every 3 h; 2) low PPFD (20 $\mu mol \cdot m^{-2} \cdot s^{-1}$) for 3 d, assay every 4 h; 3) low PPFD for 3 d, moderate PPFD (150 $\mu mol \cdot m^{-2} \cdot s^{-1}$) during assay every 4 h; 4) moderate PPFD for 3 d, assay noon and midnight. Means and standard errors were calculated for each sample treatment.

Plant Density Experiment

Azolla fronds were placed in 100 ml cups 22.8 cm^2 in surface area at various densities (1-20 fronds) in the greenhouse, photoperiod extended in the evenings to 14 h by high-pressure sodium-vapor lamps. Then they were allowed to grow further until about half of the samples were visibly crowded (2 weeks). Nutrient solution (Table 1) was changed midperiod. The acetylene reduction assay was conducted at midday in the greenhouse under ambient temperature and PPFD conditions (26°C and 1400-1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Acetylene reduction values were expressed per g dry mass. The best fit of a regression line was determined by comparing r^2 values for linear and curvilinear regression equations. The regression equation yielding the highest r^2 value was plotted together with the data points.

Combined Nitrogen Experiment

Stock solutions of KNO_3, NH_4Cl, and urea were made up at a concentration of 1.00 g $N \cdot l^{-1}$. *Azolla* fronds were weighed after a 1.0 h blot on absorbent paper towels and placed in 100 ml cups containing 3 levels of nitrogen in the standard nutrient solution (Table 1) for each source: 0, 2.0 and 10 mg $N \cdot l^{-1}$. The addition of nitrogen

compounds to the nutrient solution resulted in no discernible change in pH. After 16 d, each cup was assayed for nitrogenase activity at 29°C and 1400-1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$, then weighed. Mean relative growth rate was determined by the equation

$$RGR_{1-2} = (\ln mass_2 - \ln mass_1) \div (T_2 - T_1) \qquad \text{(Equation 2)}$$

where RGR_{1-2} is the mean relative growth rate from time 1 to time 2;

$mass_2$ and $mass_1$ are mass at the end and mass at the beginning of the experiment, respectively; and

$T_2 - T_1$ is the time interval of the experiment; in this case, expressed as days.

RESULTS AND DISCUSSION

Azolla caroliniana nitrogenase activity was strongly dependent on temperature (Figure 1). No activity occured at 0°C, and only a very small amount could be detected at 5°C. Activity rose sharply above 15°C, and reached its maximum at 25°C. Nitrogenase activity declined precipitously from 35°C to 40°C and could not be detected at 45°C.

Azolla caroliniana carries out nitrogenase activity over a wide range of PPFD levels with maximum values occuring between PPFDs of 400 and 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Figure 2). Full solar irradiance (1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was slightly but significantly ($p<0.05$) inhibitory to nitrogenase activity compared to 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Nitrogenase activity declined significantly ($p<0.05$) between 400 and 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$, between 150 and 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and between 50 and 25 $\mu mol \cdot m^{-2} \cdot s^{-1}$. *Azolla caroliniana* seems to be capable of fixing nitrogen at high or moderate levels over a wide range of light conditions characteristic of the understory of swamp forests.

Azolla caroliniana was extremely sensitive to moisture deficiency (Figure 3). Maximum nitrogenase activity occured when moisture content of *Azolla* tissue was about 88% to 95% of fresh mass and decreased to less than one fifth of the maximum at around 80% moisture content. Nitrogenase activity below 80% moisture content was negligible.

Azolla caroliniana showed a definite diurnal pattern of nitrogenase activity (Figure 4). It was very low early in the morning, climbed sharply in midmorning, and reached its peak from about 1200 to 1500 h. It then declined to a low level in the evening. In the circadian rhythm experiments there were no significant differences between day and night acetylene reduction rates under constant conditions. Nitrogenase activity went to zero within three hours and never increased in darkness, and remained constant throughout the light treatments at a level proportional to light intensity. Results indicate that *Azolla* nitrogenase activity is strictly under the control of environmental factors, especially temperature and light, and does not show endogenous patterns of activity.

Plant density markedly affected nitrogenase activity (Figure 5). A definite linear response occured over the range from 20 to 125 $g \cdot m^{-2}$ (dry mass basis). At 125 $g \cdot m^{-2}$, nitrogenase activity declined to about one sixth of the maximum value. However, on a per-area basis, the optimum stocking density of *Azolla* appears to be about 50-100 $g_{dry} \cdot m^{-2}$ (Figure 6).

Response of *Azolla caroliniana* differed with each source of nitrogen. Ammonium was the most inhibitory to *Azolla* growth; nitrate treatments caused a slight increase in growth (Table 2). *Azolla* growth was not sensitive to urea. Two mg NH_4-$N \cdot l^{-1}$ was sufficient to cause a decrease in nitrogenase activity; 10.0 mg NH_4-N or NO_3-$N \cdot l^{-1}$ caused decreased nitrogenase activity. Nitrogenase activity at the 10.0 mg urea-$N \cdot l^{-1}$ level was nearly 50% higher than that of the control. It is possible that the effects may have been due to pH changes caused by uptake of different forms of nitrogen. However, this is unlikely, because *Azolla* species are relatively insensitive to changes in pH between 5.0 and 6.0 with respect to nitrogen fixation, and have some capacity to buffer their own environments (Vu et al. 1986).

Maximum acetylene reduction values between some experiments differed due to experimental conditions. In the temperature and moisture studies, the acetylene reduction assay was conducted under fluorescent lights at PPFDs of about 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and yielded relatively low maximum nitrogenase activity values; in the other experiments, the assay was conducted under ambient greenhouse conditions. Some variation in maximum nitrogenase activity values, probably due to seasonal factors, was also found between the greenhouse assays in different experiments. These differences do not influence the response of plants within an experiment relative to the maximum value with a changing environmental factor.

The growth and nitrogenase activity response of *Azolla caroliniana* of southern Illinois is typical for most *Azolla* species worldwide. The temperature response of *Azolla caroliniana* nitrogenase is characteristic of nitrogenase in general (Alexander et al. 1974, Heath et al. 1988, Kallio 1973) and temperate species of *Azolla* in particular (Vu et al. 1986). The response of southern Illinois *Azolla* nitrogenase to PPFD does not differ markedly from that recorded for *Azolla* elsewhere (Peters et al. 1980). *Azolla caroliniana* is highly sensitive to drying as quantified in this study. The response of *Azolla* nitrogenase activity to drying has not been previously quantified. Similarly, the effects of specific *Azolla* densities on nitrogenase activity, and optimum densities for nitrogen fixation, had not previously been determined. The finding that crowding (>100 $g_{dry} \cdot m^{-2}$) adversely affects nitrogen fixation suggests that a sound aquacultural management technique for nitrogen production by *Azolla* is to thin overcrowded ponds, possibly composting or incorporating into soil the harvested excess material. *Azolla* is highly sensitive to ammonium; the presence of this ion in, for instance, farm ponds or other bodies of water subject to ammonium-rich agricultural runoff could preclude the growth of *Azolla.* Although nitrate at concentrations up to 10.0 mg $N \cdot l^{-1}$ does not seem to affect the growth of *Azolla* adversely, the reduction of nitrogenase activity associated with it indicates that in nitrate-rich waters, a large portion of the nitrogen content of *Azolla* will be nitrogen taken up from the water, not enzymatically fixed nitrogen derived from the air.

Results clearly indicate the potential of *Azolla* to fix significant amounts of nitrogen under a range of environmental conditions possible in Illinois wetland ecosystems and that ammonium is particularly inhibitory to *Azolla* nitrogen fixation. The importance of *Azolla* to the nitrogen economy of southern Illinois native wetlands, and its potential for improving wildlife habitat and as a beneficial crop in aquaculture and agriculture, merit further attention.

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Table 1. Composition of *Azolla* culture medium.

Compound	Concentration	Compound	Concentration
KCl	74.5 mg/l	H_3BO_3	1.13 mg/l
$CaCl_2 \cdot 2H_2O$	147.0 mg/l	$MnSO_4 \cdot H_2O$	0.78 mg/l
KH_2PO_4	27.1 mg/l	$ZnSO_4 \cdot 7H_2O$	0.12 mg/l
$MgSO_4 \cdot 7H_2O$	98.5 mg/l	MoO_3	0.14 mg/l
Fe as EDTA	2.5 mg/l	$CuSO_4 \cdot 5H_2O$	0.06 mg/l

Table 2. Effect of three nitrogen sources at two nitrogen concentrations on growth and acetylene reduction (ethylene evolution) of *Azolla caroliniana*.

treatment	RGR[1]	C_2H_4 evolved[2]	treatment	RGR	C_2H_4 evolved	treatment	RGR	C_2H_4 evolved
control -N	.194[a]	49.6[a]	control -N	.194[a]	49.6[a]	control -N	.194[a]	49.6[a]
NO_3-N 2mg/l	.221[ab]	63.0[a]	NH_4-N 2mg/l	.178[a]	33.2[b]	urea-N 2mg/l	.200[a]	58.2[a]
NO_3-N 10mg/l	.227[b]	29.8[b]	NH_4-N 10mg/l	.117[a]	4.6[c]	urea-N 10mg/l	.199[a]	73.8[b]

Means within a column followed by the same superscript are not significantly different ($p<0.05$).

[1] RGR is expressed as $g \cdot g^{-1} \cdot d^{-1}$.

[2] C_2H_4 evolution is expressed as $\mu mol \cdot g^{-1} \cdot h^{-1}$.

Figure 1. Effect of temperature on nitrogenase activity (acetylene reduction) in clonal *Azolla caroliniana*. (Points represent means, vertical bars represent standard errors, n=5.)

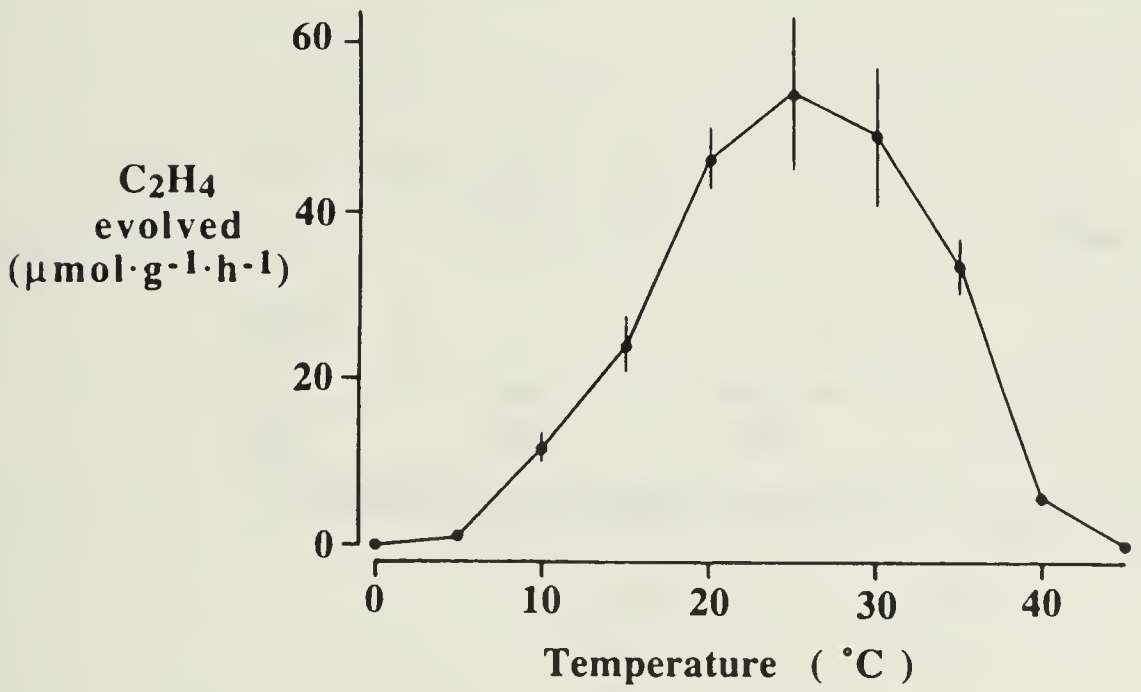


Figure 2. Effect of photosynthetis photon flux density (PPFD) on nitrogenase activity in clonal *Azolla caroliniana*. (Points represent means, vertical bars represent standard errors, n=4.)

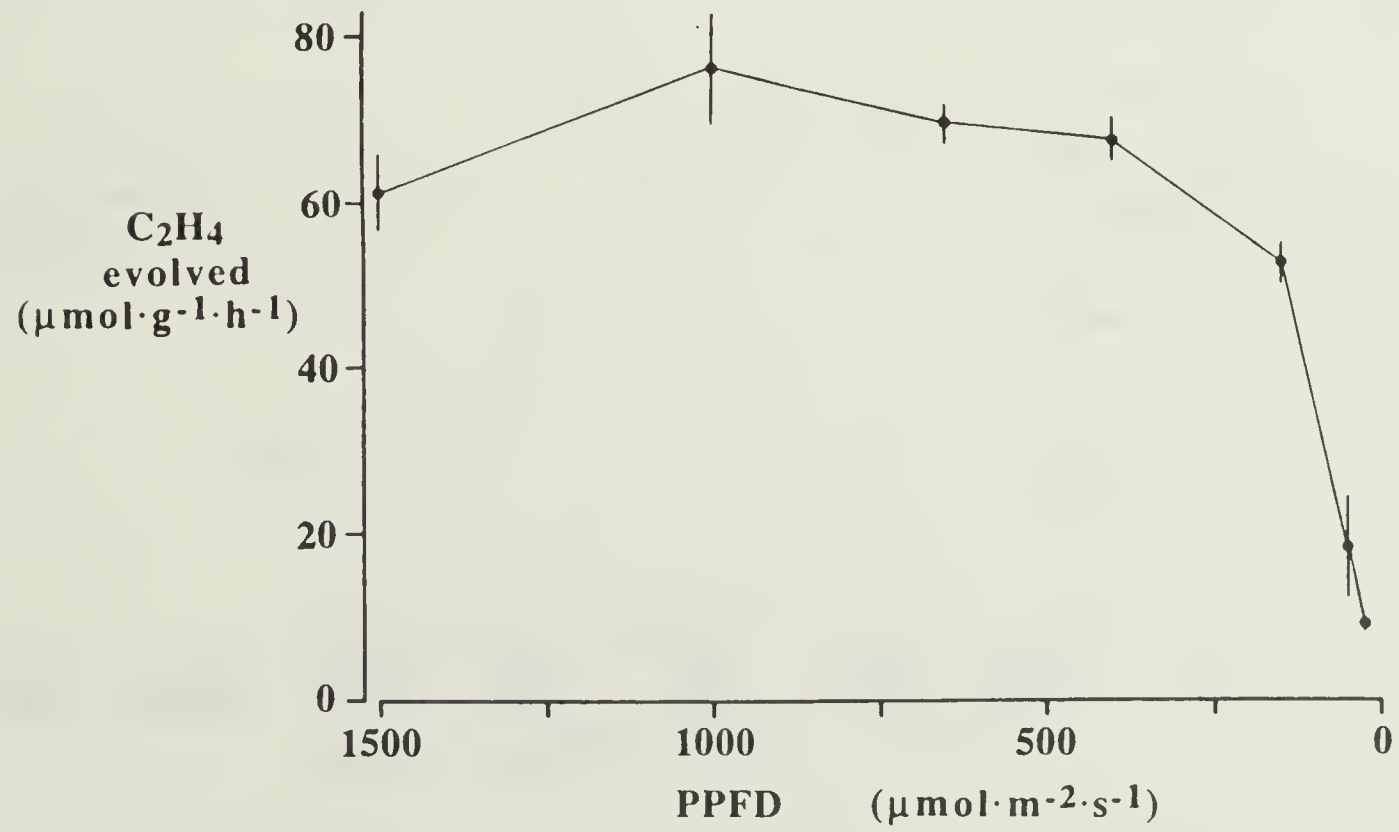


Figure 3. Effect of moisture content on nitrogenase activity in clonal *Azolla caroliniana*. (Points represent nitrogenase activities for 21 individual *Azolla* fronds at varying degrees of dessication. Regression line yielding highest r^2 value, $y = (0.24x - 16.17)^2$, shown in figure.)

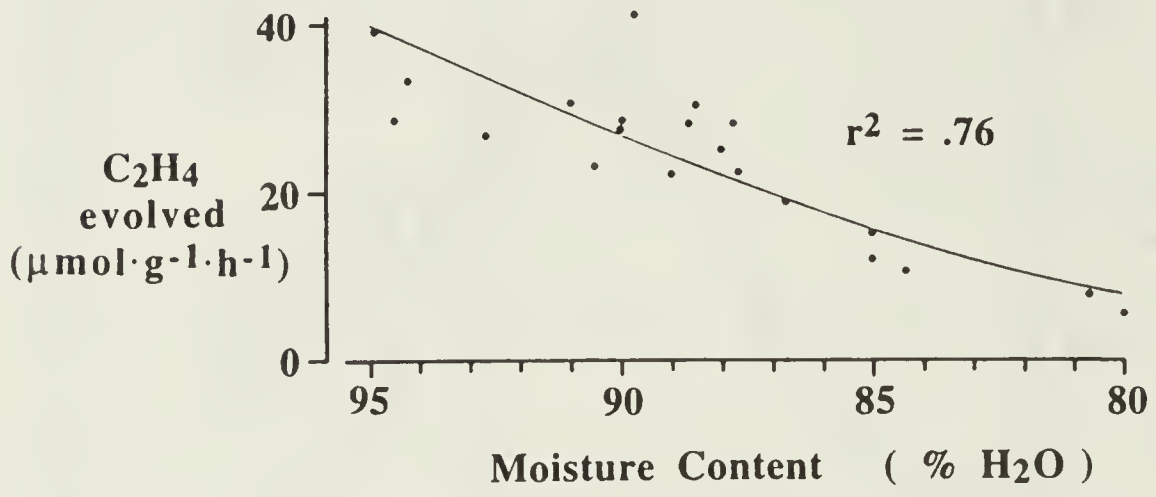


Figure 4. Diurnal pattern of nitrogenase activity in clonal *Azolla caroliniana*. (Points represent means, vertical bars represent standard errors, n=5.)

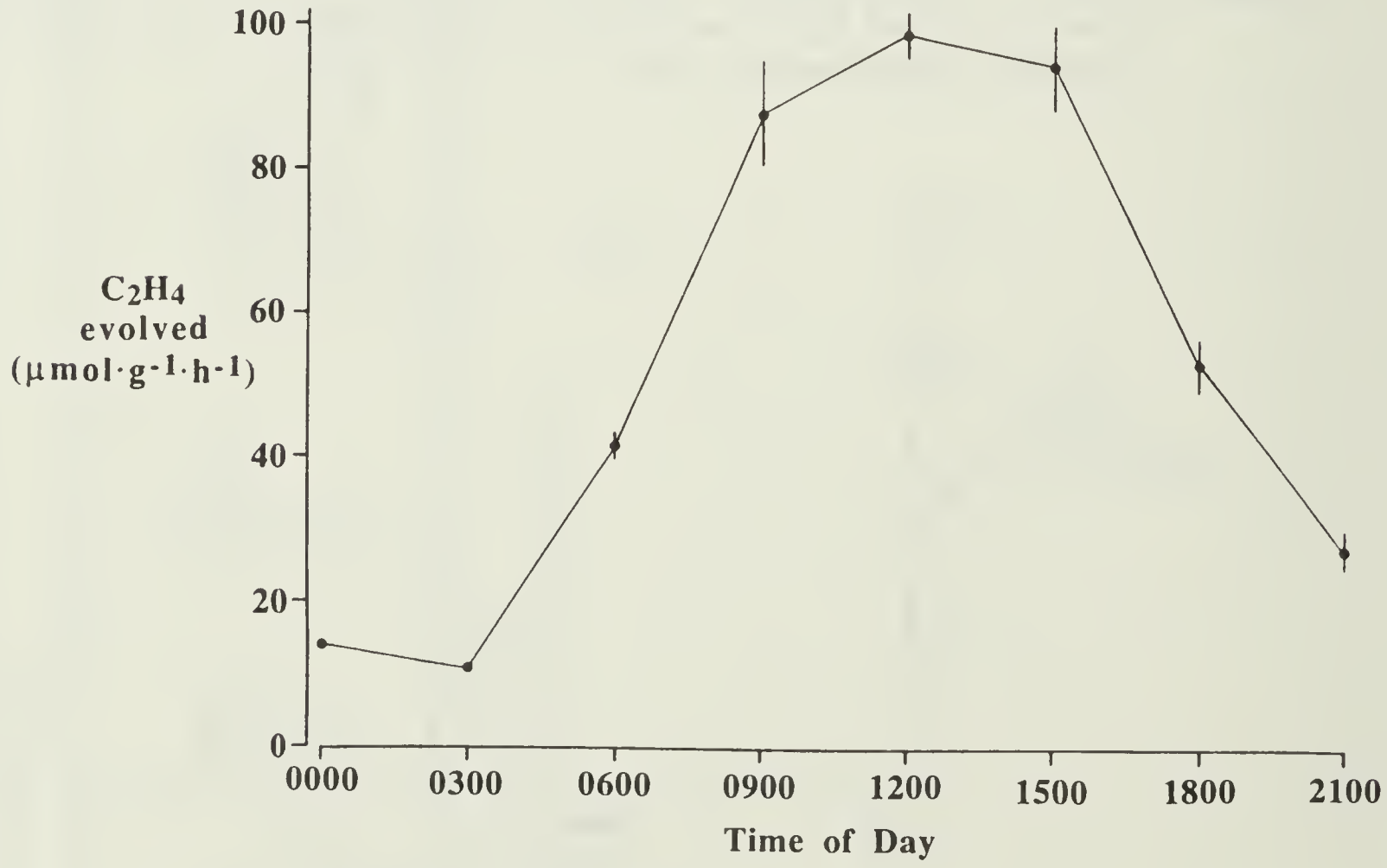


Figure 5. Effect of plant density on nitrogenase activity in clonal *Azolla caroliniana* per g dry mass of plant tissue. (Points represent nitrogenase activities for 31 samples of *Azolla* fronds at varying densities. Linear regression line yielding highest r^2 value, y = (-0.29x - 43.8), shown in figure.)

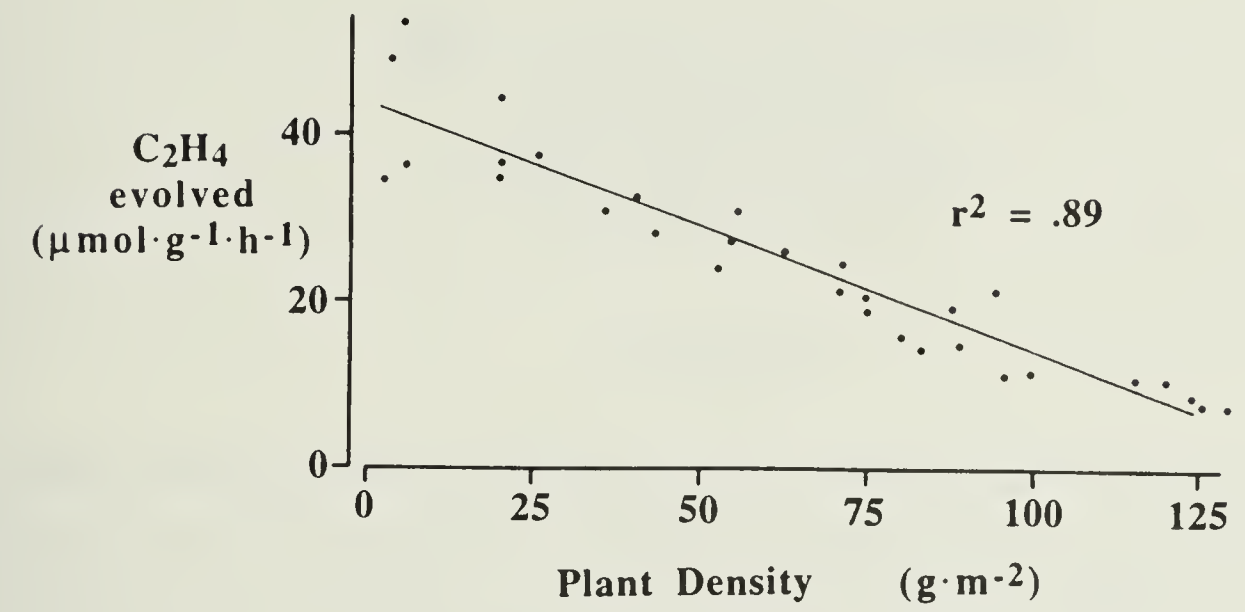
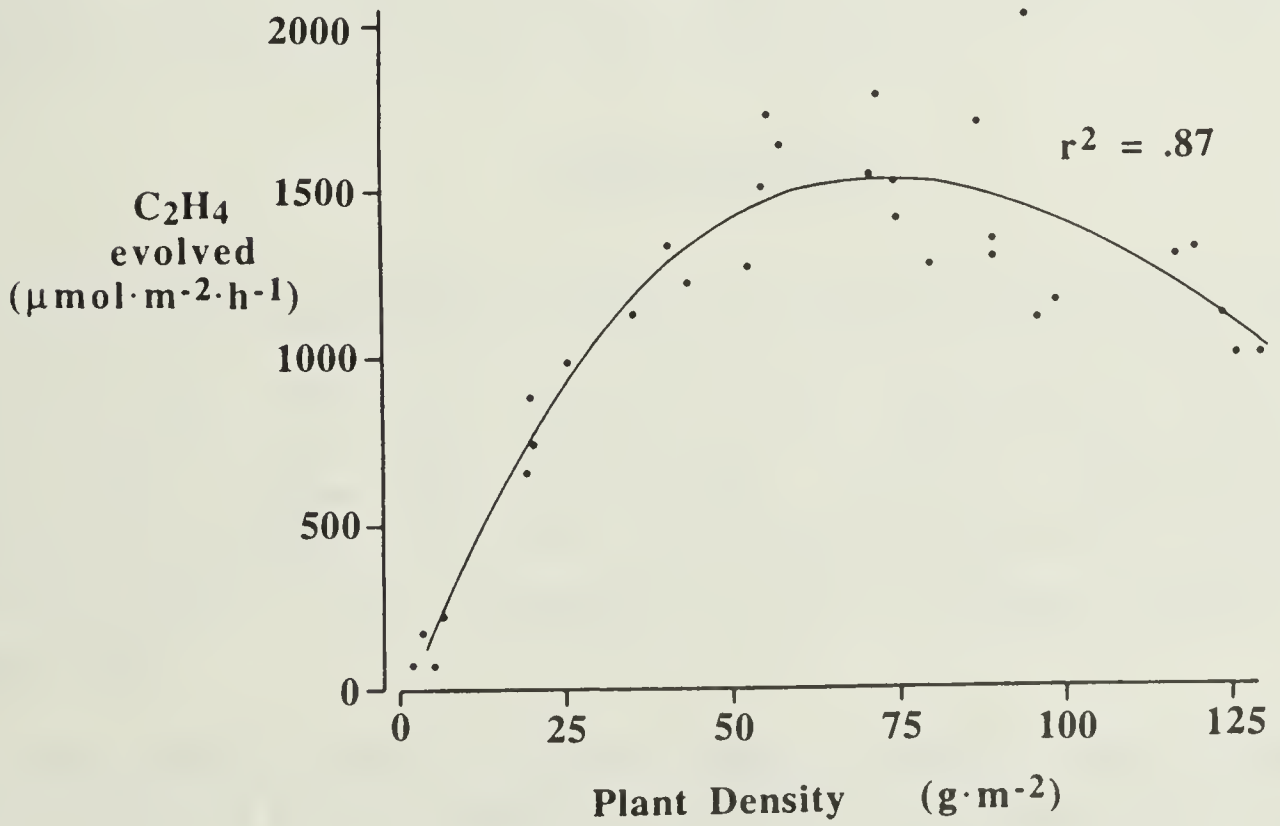


Figure 6. Effect of plant density on nitrogenase activity in clonal *Azolla caroliniana* per square meter of surface area. (Points represent nitrogenase activities for 31 samples of *Azolla* fronds at varying densities. Regression line yielding highest r^2 value, $y = -77.068 + 54.548x - 0.49535x^2 + 0.001268x^3$, shown in figure.)



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Monitoring a Savanna Restoration in East-Central Illinois

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ABSTRACT

This study monitored the effects of fire on the vegetation of a savanna restoration site at Forest Glen County Preserve, Vermilion County, Illinois. Pre-burn and post-burn inventories of the vegetation were conducted to determine changes in frequency of herbaceous species and changes in frequency and density of woody species after two successive annual fires. Post-burn survival of several tree species was also measured. Twenty-one herbaceous species exhibited significant changes in frequency after the fires. The shrubs *Rubus allegheniensis* and *Rosa multiflora* decreased significantly, while *Rubus flagellaris* increased significantly following the fires. Seedlings of *Prunus serotina* decreased significantly in frequency and density and saplings of *Prunus serotina* decreased significantly in density following the fires. Individuals ≥ 3 m tall of *Quercus alba*, *Q. imbricaria*, *Q. rubra*, *Q. velutina*, *J. nigra*, *Liriodendron tulipifera* and *Liquidambar styraciflua* were fire resistant, in contrast with individuals of *Quercus macrocarpa* which were fire resistant when > 1 m tall. This study indicates a need to protect several common native oak species from any prescribed burn until they reach at least 3 m in height.

INTRODUCTION

The deep, black soil savannas of Illinois, the vegetation continuum between forest and prairie, were dominated by oaks having between 10-80% canopy cover, with or without a shrub layer, and an herbaceous layer dominated by prairie and forest grasses and forbs (Bray 1960, White and Madany 1978, Anderson and Brown 1983, Nuzzo 1986, Anderson 1991a and 1991b). Savannas were fire and moisture dependent; the presence of fire and/or dry conditions resulted in a shift toward prairie while the absence of fire and presence of moist conditions resulted in a closed canopy forest.

Very little is known about the original savannas of Illinois. Nuzzo (1986) proposed general structures for the vegetation continuum of midwestern savannas. Anderson (1991a) outlined the conditions believed to be necessary for savanna development in presettlement time and the importance of fire frequency in its development and maintenance. Ebinger and McClain (1991) discussed the changes in a savanna community after fire suppression and McClain et al. (1993) described changes in the structure and compositions of a savanna remnant after grazing and fire.

In Illinois, few attempts have been made to restore or re-create savannas. Packard (1991) listed many species that may have been savanna components based on Mead's list (Mead 1846) and discussed some of the steps necessary for restoration. He is involved in several savanna restoration projects in northern Illinois (Breining 1993). Apfelbaum and Haney (1991) studied the restoration of degraded oak savanna remnants in northern Illinois, Indiana, and southern Wisconsin. The Illinois Department of Conservation and the Illinois Chapter of The Nature Conservancy are involved in the Funks Grove Savanna Restoration Project in McLean County (Szafoni et al. 1994). This study was initiated to describe the effects of fire on existing vegetation in an attempt to restore savanna to an area where little original natural savanna vegetation remained.

DESCRIPTION OF THE STUDY AREA

The study area is within the Forest Glen County Preserve, Vermilion County, Illinois (Sec24 T18N R11W), which is owned and managed by the Vermilion County Conservation District (VCCD). The site is 8.4 ha, triangular and on the south-central border of the VCCD property. The west side of the site is adjacent to a prairie restoration site, the south side is bordered by a plowed field, and the northeast side is bordered by a road. Across the road is a playground, beyond that is a mature second growth hardwood forest. The entire area was removed from agricultural production in 1968, and it was allowed to lie fallow until the beginning of the present study. In 1990, the area was in the perennial herb stage of old field succession with pioneer trees and shrubs becoming common in some areas.

Several old fence rows divided the site into four areas; three are approximately equal in size (NW, SW, SE) while the fourth is smaller (NE). The NW area, which generally lacked pioneer trees, had a 0.8-ha area planted to prairie species prior to the present study. The SW area was dominated by the recent growth of weedy tree species, including *Prunus serotina* (black cherry), *Juglans nigra* (black walnut), *Gleditsia triacanthos* (honey locust) and *Sassafras albidum* (sassafras). In the NE area *Quercus alba* (white oak) and *Q. imbricaria* (shingle oak) seedlings and saplings seem to have seeded in from an adjacent fence row or possibly a mature second growth hardwood forest which is in the area. The SE area had a few pioneer trees and a 1-ha wet depression in the middle, created when topsoil was removed for road construction. Two rows of *Liquidambar styraciflua* (sweet gum) and *Liriodendron tulipifera* (tulip tree) were planted on the east edge of this area in 1984.

METHODS AND MATERIALS

A prescribed burn was conducted on the entire site on March 3, 1992 and March 30, 1993. In the falls of 1991 (pre-burn), 1992 (post-burn) and 1993 (post-burn), frequency (%) of herbaceous species were determined using 0.001-ha circular plots located using a stratified random sampling procedure. Eighty-three plots were sampled in 1991, 76 in 1992 and 71 in 1993. Fisher's Exact Test ($p < 0.01$, two-tailed) was used to determine significant changes in the vegetation (Table 1,

Schefler 1988). All possible comparisons were made for each species among the samples obtained in the three years (Table 1).

The frequencies (%) and density (no./ha) of the shrubs, woody vines and tree seedlings (< 2.5 cm dbh) and tree saplings (2.5-10.0 cm dbh) were determined using 0.001-ha and 0.01-ha circular plots respectively. Plots were located using a stratified random sampling procedure. For frequency data, 83 plots were sampled in 1991, 30 in 1992 and 71 in 1993. For density data, 50 plots were counted in 1991, 30 in 1992 and 71 in 1993. Fisher's Exact Test ($p < 0.01$, two-tailed) was used to determine significant changes in the frequency data (Table 2). All possible comparisons were made for each species among the samples obtained in the three years. Shrub and woody vine densities were not recorded in 1991. Student's T-test ($p < 0.01$, two-tailed) was used to compare the two-year shrub density data (Table 2, Schefler 1988). One-way ANOVA ($p < 0.01$) and Duncan's Multiple-Range Test were used to compare three year density data (Table 2, Schefler 1988). Total stem counts of shrubs and vines were compared using Student's T-test ($p < 0.01$, two-tailed) and total stem counts of tree seedlings and saplings were compared using one-way ANOVA ($p < 0.01$, Table 2, Schefler 1988).

Tree survival after the first fire (1992) was determined originally using four categories: not top-killed, top-killed not resprouting, top-killed resprouting from the base and top-killed resprouting from the trunk. Data were then categorized into top-killed and not top-killed and two height classes (< 3 m and ≥ 3 m). Fisher's Exact Test ($p < 0.01$, two-tailed) was used to determine if species differed significantly in their ability to survive a burn by comparing the proportion of top-killed and not top-killed stems in the two height classes (Table 3). *Quercus velutina* and *Q. rubra* were combined for analysis because of their low stem counts.

In the spring of 1993, the ages of two height classes were determined. Trees ≥ 3 m tall were aged by counting growth rings on cores taken at 137 cm above the ground with an increment borer. Cross-sections of trees < 3 m tall were made at ground level. Their ages were determined in the laboratory. Five years were added to those ≥ 3 m tall to adjust for the sampling height (Table 4). Plant nomenclature follows Mohlenbrock (1986).

RESULTS AND DISCUSSION

Burns

Dry weather and a moderate fuel load resulted in a hot, intense fire on March 3, 1992. Compared to the 1992 fire, the 1993 fire was not as hot and intense due to heavy spring rains and a reduced fuel load. Consequently, the fire skipped many small wet areas, and the vegetation in general did not burn as completely as in 1992.

Herbaceous Species

A total of 77 herbaceous species were present in the plots (Table 1). *Carex* species were not differentiated. The species with the highest frequencies in 1991, *Solidago canadensis* (99%), *Poa pratensis* (71%), *Cirsium discolor* (70%), *Festuca pratensis* (65%) and *Aster pilosus* (63%), are all species of old fields and disturbed areas. In

1992, these same plants were the most frequent species except the introduced legume, *Trifolium pratense* (87%), had the second highest frequency. In 1993, *Solidago canadensis* (97%) was again the most frequent species; *Desmodium glabellum* (73%) and *Ambrosia artemisiifolia* (56%) increased in frequency, while *Trifolium pratense* (58%), *Cirsium discolor* (56%), *Poa pratensis* (17%) and *Aster pilosus* (31%) all decreased.

Of the 68 species sampled between 1991 and 1992, eight significantly increased while three significantly decreased (Table 1). Seventy-seven species were sampled between 1991 and 1993. Seven of these species significantly increased and seven significantly decreased (Table 1). Seventy-seven species were also sampled between 1992 and 1993, of which five significantly increased and five significantly decreased (Table 1). *Trifolium pratense* and *Dichanthelium acuminatum* significantly increased between 1991 and 1992, and then significantly decreased in 1993 (Table 1).

Four legumes, both native and introduced, increased after the fires. Anderson and Schwegman (1971, 1991) and Anderson and Van Valkenburg (1977) all obtained similar results, with increases in legume frequency after burns in barren communities in southern Illinois. Many of the species that increased in frequency are native prairie species that are adapted to fire. Most are perennials but *Ambrosia artemisiifolia* is a native annual well-adapted to colonizing disturbed habitats such as bare soil that is common after fires (Anderson and Van Valkenburg 1977 and Anderson and Schwegman 1991). Most of the species that increased are not considered high quality prairie or savanna species.

Of the species that decreased in frequency, four are introduced: *Achillea millefolium*, *Dactylis glomerata*, *Dianthus armeria* and *Poa pratensis*. The others that decreased are native, open forest or disturbed habitat species that probably are also not well-adapted to fire. The reason for the decrease in frequency of the native prairie species (*Aster pilosus*, *Oenothera biennis*, *Solidago nemoralis)* is not known although some prairie species do decline following fire. Anderson and Van Valkenburg (1977) recorded a similar decrease in *Solidago nemoralis* after a prescribed burn on a barren in southern Illinois.

Woody Species

The shrub *Rubus allegheniensis* had the highest frequency all three years followed by *Rosa multiflora* (Table 2). Both species decreased in frequency the third year of the study. *Rubus flagellaris* increased in frequency both years; Anderson and Van Valkenburg (1977) recorded an increase in this species after a prescribed burn on a barren in southern Illinois. This increase may have been stimulated by the fires. Except for *Rosa multiflora* and *Elaeagnus umbellata*, all are native species that probably were components of the savanna shrub layer (Ebinger 1986 and 1987). The decrease in total stems between years was not statistically significant.

Seedlings of 20 tree species were present on the site; most are native forest species. *Prunus serotina* was the most frequently encountered species in all three years and it had the highest density in pre-burn data of 1991. *Juglans nigra* ranked second in

frequency and density in 1991 followed by *Sassafras albidum*. *Prunus serotina* significantly decreased in density between 1992 and 1993. It is not fire resistant, probably accounting for much of this decrease. *Sassafras albidum* increased due largely to sprouting in 1992 and then decreased in 1993. This species commonly forms root sprouts after fires. Anderson and Van Valkenburg (1977) also recorded a large increase in *Sassafras albidum* sprouts after a single fire on a barren community in southern Illinois. Much of the increased density was probably a result of this ability to root sprout, while the subsequent decrease may have been due to a decline in stem vigor after the second fire. *Malus ioensis*, a savanna component, was fairly important on the site in 1991 and 1992, but showed a major decline after two fires. Few oak seedlings were encountered during the study, though occasional individuals of *Quercus alba*, *Q. imbricaria*, *Q. macrocarpa*, *Q. velutina* and *Q. rubra* were found. Total seedling density varied from 2520 individuals in 1991 to 2701 in 1992, to 703 in 1993. The increase between 1991 and 1992 was due to the large increase in the number of stems of *Sassafras albidum* and a doubling of the stems of *Malus ioensis*. The decrease between 1992 and 1993 was the result of a major decrease in the stems of all species. Anderson and Schwegman (1991) recorded a similar decrease in stems after prescribed fire on a barren community in southern Illinois.

Of the twelve tree sapling species encountered, *Prunus serotina* had the highest frequency and density in all three years of the study, and was the only species to show significant differences among years (Table 2). The decreases in frequency and density of this species were probably caused by fires. Of the remaining saplings (11 species), all had extremely low frequencies and densities. From a high of 216 stems per ha in 1991, sapling density decreased to less than a quarter of that number in 1992 and 1993 (Table 2). In most instances these decreases could be directly attributed to fires, as many dead stems were observed after the fires (Anderson and Schwegman 1991).

Tree Survival and Age

Because the savanna restoration site had not been burned since being removed from agricultural production in 1968, it was possible to measure the effects of fire on eight tree species. Due to the lack of prairie grasses the fuel load was less than that of a mature prairie. The results indicate that most individuals $\geq$ 3 m tall were not top-killed, surviving the fire with minimal damage (Table 3). In contrast, individuals $<$ 3 m tall usually were top-killed, the majority resprouting from the base or trunk. The difference in fire resistance by height class was statistically significant for all eight tree species (Table 3). *Quercus macrocarpa* appeared to be the most fire resistant: five individuals less than 1 m tall were top-killed while taller individuals survived with little or no damage.

The average ages for individuals 2-3 m tall were: *Quercus alba*, 11.5 years old; *Q. imbricaria*, 7.3 years; and *Q. macrocarpa*, 13.0 years (Table 4). Individuals 5 to 7 m tall were not adversely affected by the fire and were between 17 and 19 years of age (Table 4). This indicates that oaks used in savanna restoration should be protected from fires until they are more than 3 m tall and 8 to 12 years old.

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Table 1. Pre-burn (1991, n = 83) and post-burn (1992, n = 76; 1993, n = 71) frequency (%)of herbaceous species at the savanna restoration site, Forest Glen Preserve, Vermilion County, Illinois. Species with a frequency of less than 5% are not included.

Species	Frequency (%) 1991	1992	1993
Significant increase in frequency			
Agalinis tenuifolia (Vahl) Raf.	0	*21	+34
Ambrosia artemisiifolia L.	0	*26	+~56
Apocynum cannabinum L.	0	0	+~11
Asclepias syriaca L.	4	1	~14
Cassia fasciculata Michx.	0	*14	+~35
Carex ssp.	4	*33	15
Desmodium glabellum (Michx.) DC.	1	*30	+~73
Euthamia graminifolia (L.) Salisb.	1	*12	8
Lespedeza virginica (L.) Britt.	0	8	+18
Solidago juncea Ait.	1	*36	+31
Sorghastrum nutans (L.) Nash	14	*32	21
Significant decrease in frequency			
Achillea millefolium L.	10	17	+~0
Aster pilosus Willd.	63	74	+~31
Dactylis glomerata L.	17	*0	+3
Dianthus armeria L.	8	*0	0
Geum canadense Jacq.	24	17	+~0
Oenothera biennis L.	36	*0	+3
Poa pratensis L.	71	66	+~17
Solidago nemoralis Ait.	40	50	+~17
Significant increase followed by significant decrease			
Dichanthelium acuminatum (Sw.) Gould & Clark	7	*32	~6
Trifolium pratense L.	19	*87	+~58
Species exhibiting no significant changes			
Andropogon gerardii Vitman	4	5	10
Andropogon virginicus L.	6	12	8
Antennaria plantaginifolia (L.) Richardson	7	8	0
Aristida oligantha Michx.	5	8	7
Asclepias verticillata L.	0	0	7
Baptisia lactea (Raf.) Thieret.	11	4	11
Cirsium discolor (Muhl.) Spreng.	70	62	56
Daucus carota L.	49	49	55
Desmodium sessilifolium (Torr.) Torr. & Gray	0	0	6
Elymus canadensis L.	8	9	8
Elymus hystrix L.	19	16	17
Eupatorium serotinum Michx.	20	9	17
Festuca pratensis Huds.	65	63	69
Fragaria virginiana Duchesne	29	22	20
Helianthus mollis Lam.	12	13	17
Hypericum punctatum Lam.	7	0	0
Lespedeza capitata Michx.	8	11	8
Melilotus alba Medic.	8	4	8
Pastinaca sativa L.	7	4	4
Phleum pratense L.	48	54	59
Potentilla simplex Michx.	0	7	1
Pycnanthemum tenuifolium Schrad.	6	8	1
Ratibida pinnata (Vent.) Barnh.	5	4	7
Rudbeckia hirta L.	7	1	0
Schizachyrium scoparium (Michx.) Nash	8	9	10
Solidago canadensis L.	99	97	97
Vernonia gigantea (Walt.) Trel.	5	4	1

* = significant difference between 1991 and 1992
+ = significant difference between 1991 and 1993
~ = significant difference between 1992 and 1993

Table 2. Pre-burn (1991, n = 50) and post-burn (1992, n = 30; 1993, n = 71) frequency(%) and density (no./ha) for shrubs, vines, tree seedlings and saplings at the savanna restoration site, Forest Glen Preserve, Vermilion County, Illinois.

	Frequency (%)			Density (no./ha)				
Species	1991	1992	1993	1991	1992	1993	Fcal	p
Shrubs and Vines								
Rubus allegheniensis Porter	66	*93	~56	---	14467	3197		
Rosa multiflora Thunb.	30	40	~15	---	700	310		
Rubus flagellaris Willd.	0	10	+32	---	1000	1211		
Toxicodendron radicans (L.) Kuntze	8	10	20	---	433	---		
Rubus occidentalis L.	8	5	8	---	---	592		
Elaeagnus umbellata Thunb.	4	0	0	[1]40a	0a	0a	2.028	0.1340
Others (3 species)	1	3	3	---	67	28		
Totals				---	16667	5338		0.3770
Tree Seedlings								
Prunus serotina Ehrh.	30	33	+13	1380a	667b	211b	7.97	0.0005
Juglans nigra L.	13	0	6	420a	0b	56b	4.93	0.0081
Sassafras albidum (Nutt.) Nees	13	27	10	160a	1700a	338a	2.75	0.0660
Malus ioensis (Wood) Britt.	7	13	1	120a	267a	14a	1.14	0.3202
Gleditsia triacanthos L.	5	0	1	160a	0a	28a	1.24	0.2889
Quercus imbricaria Michx.	2	0	3	40a	0a	28a	1.01	0.3644
Others (14 species)	12	7	2	240	67	28		
Totals				2520a	2701a	703a	3.37	0.0361
Tree Saplings								
Prunus serotina Ehrh.	24	13	13	172a	17b	25b	8.58	0.0003
Juglans nigra L.	4	0	3	8a	0a	3a	1.53	0.2183
Sassafras albidum (Nutt.) Nees	5	10	6	8a	10a	13a	0.83	0.4344
Malus ioensis (Wood) Britt.	1	0	0	4a	0a	0a	0.99	0.3696
Quercus alba L.	4	0	0	6a	0a	0a	3.08	0.0477
Quercus imbricaria Michx.	1	0	0	2a	0a	0a	0.99	0.3696
Others (6 species)	7	10	0	16	16	0		
Totals				216a	43b	41b	10.11	0.0001

* = significant difference between 1991 and 1992
+ = significant difference between 1991 and 1993
~ = significant difference between 1992 and 1993
[1] significant differences between densities were noted by using different lower case letters

Table 3. The number of trees top-killed by height classes (m) for the dominant tree species at the savanna restoration site, Forest Glen Preserve, Vermilion County, Illinois.

	Height Classes (m)	Not Top-killed	Top-killed
Quercus alba L. *	< 3	2	8
	≥ *3*	*25*	*1*
Quercus imbricaria Michx. *	< 3	7	86
	≥ 3	80	11
Quercus macrocarpa Michx. *	< 3	7	5
	≥3	27	0
Quercus velutina Lam. and	< 3	2	6
Q. rubra L. *	≥3	24	1
Juglans nigra L. *	< 3	58	204
	≥ 3	93	2
Liriodendron tulipifera L. *	< 3	20	12
	≥ 3	48	1
Liquidambar styraciflua L. *	< 3	3	15
	≥ 3	37	1

* = significant difference between height classes

Table 4: Tree age (years), diameter at breast height (cm), basal diameter (cm) and tree height (m) of three species of trees at the savanna restoration site, Forest Glen Preserve, Vermilion County, Illinois.

	Number of Individuals	Tree Height (m)	Ave DBH (cm)	Ave. Basal Diameter (cm)	Ave. Age (years)
Quercus alba L.	2	< 3	---	4.25	11.5
	7	5-7	11.9	---	17.3
Quercus imbricaria	3	< 3	---	2.4	7.3
Michx.	5	5-7	12.7	---	18.2
Quercus macrocarpa	2	< 3	---	3.6	13.0
Michx.	7	5-7	15.8	---	19.0

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Naturalized *Forsythia suspensa* (Thunb.) Vahl (Oleaceae) in Illinois

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ABSTRACT

Forsythia suspensa (Thunb.) Vahl. is reported as naturalized within the canyon of a tributary to the Vermilion River in Matthiessen State Park, LaSalle County, Illinois. This is the first reported naturalization of this species in eastern United States.

While undertaking a study of endangered and threatened plant species at Matthiessen State Park, near Oglesby and Utica, LaSalle County, Illinois, the senior author observed two populations of *Forsythia suspensa* (Thunb.) Vahl (weeping forsythia). This species is a relatively common ornamental shrub native to China that has been planted in the northeastern United States since 1833 (Rehder 1940). According to Fernald (1950) and Gleason and Cronquist (1991) it has not become naturalized and no mention of this species has been found in the many regional and state floras examined by the authors. Swink and Wilhelm (1994) have reported *F. x intermedia* Zabel as naturalized in a sandy blowout near old homesites at Indiana Dunes State Park, Porter Co., Indiana. This medium sized shrub rarely exceeds 2 m in height, has pendulous branches with hollow internodes and solid nodes, while the opposite, irregularly serrated leaves are usually simple, but 3-lobed and trifoliate forms are also found. The flowers are golden yellow, to 2.5 cm long, while the narrowly ovoid, woody, septicidally dehiscent capsule has many winged seeds (Bailey 1949, Rehder 1940).

Generally, propagation of this species is by softwood cutting in summer, by hardwood cutting in autumn and winter, by seeds, and by branches taking root at the tips where they touch ground and send out vigorous shoots (Flint 1983). According to Dirr (1983) seeds will germinate without pre- treatment, but 1-2 months at 41° F appear to improve germination.

The two populations discovered were in a narrow, deep canyon cut through St. Peter Sandstone (Willman and Payne 1942). Subsequent searches failed to locate additional colonies, though similar habitat occurred throughout this nearly mile long canyon. The smaller population, located about 150 m down stream from Cascade Falls, consisted of seven individuals located about 5 m up the east-facing, vertical cliff-face (Ebinger #26416A, EIU). All were connected by drooping, stoloniferous branches, and probably originated from one plant. Some of these pendulous branches nearly touched the stream bed. Associated species on the cliff-face included *Hydrangea arborescens* L., *Ribes missouriense Nutt.*, *Parthenocissus quinquefolia* (L.) Planch., *Pilea pumila* (L.) Gray, *Cystopteris bulbifera* (L.) Bernh., *Aralia racemosa* L., *Aruncus dioicus* (Walt.) Fern. and *Pellaea atropurpurea* (L.) Link.

The larger population, located about 50 m upstream from the smaller population, consisted of 25 plants growing on a talus mound covered with a thin layer of soil (Ebinger #26416B, EIU). All plants were in an area 6 m by 8 m, and probably were the result of asexual reproduction from pendulous branches rooting at the tips of one original individual. Associated shrubs included *Hydrangea arborescens*, *Ptelea trifoliata* L. and *Ribes missouriense*, along with the naturalized *Ligustrum vulgare* L. and *Berberis thunbergi* DC. Few herbaceous species were found associated with the colony, and due to the dense shade, only a few individuals of these taxa were observed. These included *Aruncus dioicus*, *Aster lateriflorus* (L.) Britt., *Cryptotaenia canadensis* (L.) DC., *Laportea canadensis* (L.) Wedd., *Leersia virginica* Willd., *Pilea pumila* and *Rudbeckia laciniata* L.

No ornamental plantings of *Forsythia* spp. were found in the area. However, the area has been used as a park since the last century because of its picturesque canyons and diverse plant and animal life. The area was privately owned from the 1890's until 1942 when the heirs of the prominent LaSalle industrialist F. W. Matthiessen donated the property to the State of Illinois. Prior to 1942 the area was known as Deer Park (Matthiessen State Park Files, Illinois State Archives), and numerous ornamental trees and shrubs were planted, many of which are still present, with some having become naturalized.

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New Mixed-metal Polyhydride Compounds Containing the Ag_2Re and Ag_2Re_2 Cores

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ABSTRACT

The reaction of $ReH_5(PPh_3)_3$ with AgX (X = PF_6^- or NO_3^-) produces the mixed silver rhenium polyhydride compounds, $[Ag_2ReH_5(PPh_3)_3]X_2$. The compound $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ has been found to react with alkenes such as cyclohexene, 1-pentene, or styrene to produce $[AgReH_4(PPh_3)_3]_2$ and finely divided silver metal.

INTRODUCTION

The synthesis of mixed-metal polyhydride clusters is an area of continuing interest. These mixed metal polyhydride clusters may afford one or more metal centers to coordinate organic substrates while the second metal center may provide hydride ligands to effect organic transformations. The goal of this work was to synthesize and investigate such a complex.

Previous work with the ReH_5L_3 (L = tertiary phosphine) class of polyhydride compounds has shown that these compounds readily form mixed metal polyhydride clusters *via* acid-base type reactions (Moehring and Walton, 1988; Carr, Fontaine, and Shaw, 1991). Other work has demonstrated that a silver containing polyhydride compound can contain a reactive, and possibly coordinativley unsaturated, silver center (Connelly, Howard, Spencer, and Woodley, 1984). We chose to pursue the reaction of silver salts with $ReH_5(PPh_3)_3$ in an attempt to obtain a reactive silver center bound to a rhenium polyhydride fragment. We found that $ReH_5(PPh_3)_3$ reacted with the silver salts AgX (X = PF_6^- or NO_3^-) to produce $[Ag_2ReH_5(PPh_3)_3]X_2$. A subsequent examination of the reactivity of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ found that alkenes would abstract one silver center per complex to produce $[AgReH_4(PPh_3)_3]_2$.

MATERIALS

Starting Materials

The complex $ReH_5(PPh_3)_3$ was prepared by the standard literature method (Cameron, Moehring, and Walton, 1990; Chatt and Coffey, 1969). All other reagents and solvents were obtained from commercial sources. Solvents were deoxygenated and/or distilled prior to use. All reactions were carried out under an atmosphere of nitrogen.

$[Ag_2ReH_5(PPh_3)_3](PF_6)_2$

Dichloromethane, 5 mL, was added to a flask which contained $AgPF_6$, 0.0515 g, (0.204 mmol) and $ReH_5(PPh_3)_3$, 0.1000 g (0.1022 mmol). The resultant yellow solution was stirred for 30 minutes and precipitation was then induced by the addition of 100 mL of diethyl ether. The resultant precipitate was filtered, washed with diethyl ether, and dried under vacuum; yield 0.0800 g (53%). Anal. Calcd for $C_{54}H_{50}Ag_2F_{12}P_5Re$: C, 43.71; H 3.40. Found: C, 44.25; H 3.79.

$[Ag_2ReH_5(PPh_3)_3](NO_3)_2$

A 50 mL round bottomed flask was loaded with 0.1010 g of $ReH_5(PPh_3)_3$ (0.1032 mmol) and 0.0960 g of $AgNO_3$ (0.565 mmol). Diethyl ether, 30 mL, was added and the mixture was stirred for 2.5 hours. A tan precipitate was isolated by filtration. The precipitate was extracted into 10 mL of dichloromethane. A white precipitate of $[Ag_2ReH_5(PPh_3)_3](NO_3)_2$ was induced from the extract by addition of 100 mL of pentane. The product was filtered and dried under vacuum; yield 0.0770 g (57 %). Anal. Calcd for $C_{54}H_{50}Ag_2N_2O_6P_3Re$: C, 49.21; H 3.82. Found: C, 48.43; H 4.31.

$[AgReH_4(PPh_3)_3]_2$

This compound can be prepared using a similar procedure and any of the following alkenes: cyclohexene, 1-pentene, or styrene. This procedure is given for styrene. In a 50 mL round bottomed flask, 0.0463 g of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ (0.031 mmol) was dissolved in 5 mL of dichloromethane. To this solution, 0.5 mL of styrene (3.8 mmol) was added. The solution was stirred for 16 hours and a precipitate of silver metal was removed by filtration. Diethyl ether, 100 mL, and pentane, 25 mL, were added to the filtrate to induce precipitation. The product was collected by filtration and dried under vacuum; yield 0.0293 g (87 %). Anal. Calcd for $C_{108}H_{98}Ag_2P_6Re_2$: C, 59.78; H 4.55. Found: C, 60.71; H 3.97.

Physical Measurements

Infrared spectra were recorded as Nujol mulls between KBr plates on a Mattson Galaxy 2020 FT-IR spectrophotometer. Cyclic voltammetric experiments were performed with a Princeton Applied Research Model 173 potentiostat. A Pt disk working electrode was used. Dichloromethane was used as the solvent and the supporting electrolyte was 0.1 M tetrabutylammonium hexafluorophosphate. Potentials are uncorrected for junction potentials. Under our experimental conditions, $E_{1/2}$ = +0.47 V versus a Ag/AgCl reference electrode for a dichloromethane solution of ferrocene. ^{31}P NMR spectra were obtained on a Varian XL-200 spectrometer operated at 80.98 MHz using an internal deuterium lock and 85 % H_3PO_4 as an external standard. Positive chemical shifts were measured downfield from H_3PO_4. ^1H NMR spectra were recorded at 60 MHz on a Hitachi Perkin Elmer R-24 B spectrometer or at 200 MHz on a Varian XL-200 spectrometer. Conductivity measurements were made with a Lab-Line Instruments Model MC-1 conductivity bridge. Microanalyses were performed by National Chemical Consulting Inc., Tenafly, New Jersey.

RESULTS AND DISCUSSION

The reaction of $ReH_5(PPh_3)_3$ with AgX (X = PF_6^- or NO_3^-) results in the mixed silver rhenium polyhydride complex $[Ag_2ReH_5(PPh_3)_3]X_2$; which is an interesting addition to the mixed-metal polyhydride compounds formed by combining ReH_5L_3 with gold or silver containing compounds. The mixed-metal cores Au_2Re, AuRe, and AgRe have previously been prepared in a similar fashion (Moehring and Walton, 1988; Carr, Fontaine, and Shaw, 1991). Unlike other such gold or silver containing cores, however, $[Ag_2ReH_5(PPh_3)_3]X_2$ does not contain a tertiary phosphine bound to silver. The compounds $[Ag_2ReH_5(PPh_3)_3]X_2$ most likely have silver atoms supported by significant interactions with the anions PF_6^- or NO_3^-. The reactivity of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ with alkenes, which leads to the loss of one silver center and the formation of $[AgReH_4(PPh_3)_3]_2$, is consistent with silver centers that are supported by easily displaced ligands.

The Nujol mull infrared spectrum of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ includes a very weak metal-hydride stretch at 1680 cm^{-1} and a weak absorption at 837 cm^{-1} due to the PF_6^- anion. We attribute the weakness of the PF_6^- absorption to interaction between the anion and the silver center. This interaction would effectively disturb the symmetry of the anion. The Nujol mull infrared spectrum of the nitrate salt exhibits a similar metal hydride stretch at 1680 cm^{-1}, but the absorption at 837 cm^{-1} is, of course, absent.

The ^1H NMR spectra of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ and $[Ag_2ReH_5(PPh_3)_3](NO_3)_2$, recorded in $CDCl_3$, are identical. The spectra consist of resonances at 7.2 ppm due to phenyl protons and resonances at -5.23 ppm due to the hydride ligands (Figure). The two resonances integrate as five hydride ligands for each three triphenylphosphine ligands. The hydride resonance is an apparent sextet which is best explained as an overlapping quartet of triplets. The quartet arises from hydride coupling to the three ^{31}P nuclei (J_{PH} = 17 Hz) and the triplet arises from hydride coupling with the two silver nuclei. Coupling to individual silver isotopes is not observed. The mean silver-hydride coupling constant is 20 Hz.

The ^{31}P NMR spectrum of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$, recorded in $CDCl_3$, consists of a singlet at 25.5 ppm due to the rhenium bound phosphorous atoms and a septet at -142.9 ppm due to the PF_6^- phosphorous atoms. As with all other silver containing rhenium polyhydride compounds, no coupling is observed between rhenium bound phosphorous nuclei and silver atoms (Carr, Fontaine, and Shaw, 1991; Connelly, Howard, Spencer, and Woodley, 1984).

Conductivity measurements of $[Ag_2ReH_5(PPh_3)_3]X_2$ solutions correspond to the formulation of $[Ag_2ReH_5(PPh_3)_3]X_2$ as a 2:1 electrolyte. In acetone, $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ produced a specific conductance, Λ, of 182 $ohm^{-1}cm^2mol^{-1}$ and $[Ag_2ReH_5(PPh_3)_3](NO_3)_2$ produced a specific conductance of 190 $ohm^{-1}cm^2mol^{-1}$ (Geary, 1971).

Other evidence in support of the formulation $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ includes the yields from reactions of $ReH_5(PPh_3)_3$ with varying amounts of $AgPF_6$. At

stoichiometries of less than two equivalents of $AgPF_6$ per equivalent of $ReH_5(PPh_3)_3$, the yield of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ decreased in proportion to the amount of $AgPF_6$ used. No effect upon the yield of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ was observed when stoichiometries of two or more equivalents of $AgPF_6$ were used. All attempts to isolate or observe other rhenium containing compounds from the above reactions were unsuccessful. We have no evidence of the fate of the unrecovered rhenium, be it unreacted starting material, unrecovered product, or some other rhenium containing product(s).

The compounds $[Ag_2ReH_5(PPh_3)_3]X_2$ exhibit electrochemistry which is very different from that of the $ReH_5(PPh_3)_3$ starting material. $ReH_5(PPh_3)_3$ has a first oxidation potential, as measured by cyclic voltammetry, of +0.37 V versus SCE (Allison, Cameron, Wild, and Walton, 1981). The cyclic voltammogram of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ is characterized by an irreversible oxidation ($E_{p,a}$ = +1.70 V) and an irreversible reduction ($E_{p,c}$ = -1.05 V) with an associated product wave ($E_{p,a}$ = +0.29 V). The increase in first oxidation potential between the starting $ReH_5(PPh_3)_3$ and the $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ product of +1.33 V is very similar to the reported +1.35 V shift observed for the compound $Re_2H_8(PPh_3)_4$ and its bis coinage metal adduct, $[Re_2H_8(PPh_3)_4(AuPPh_3)_2](PF_6)_2$ (Moehring, Fanwick, and Walton, 1987).

As mentioned earlier, we were interested in preparing compounds such as $[Ag_2ReH_5(PPh_3)_3]X_2$ because we wanted to study their reactivity. An interaction between PF_6^- and silver, which was indicated in the infrared spectrum of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$, suggested the possibility of a reactive site at silver. We, therefore, chose to pursue the reactions of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ with alkenes. Alkenes have previously been shown to interact rather strongly with silver ions (Hartley, 1973; Crookes and Wolf, 1973). We found that the reactions of cyclohexene, 1-pentene, or styrene with $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ all produced the same rhenium containing product, namely $[AgReH_4(PPh_3)_3]_2$. These reactions also produce finely divided metallic silver as a gray precipitate. The silver precipitate has been identified by wet chemical tests. The silver most likely arises from reduction of a putative $[Ag(alkene)_n]^+$ complex formed during the reaction. Thus, $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ does indeed contain a reactive silver center. Interaction of an alkene at the center, however, leads to disruption of the silver rhenium bond and concomitant loss of silver from the complex.

This is not the first example of the removal of coinage metals from mixed coinage metal rhenium polyhydride compounds. The $(AuPR_3)^+$ (R = Ph or Et) fragments of $[Re_2H_8(PPh_3)_4(AuPR_3)]PF_6$ and $[Re_2H_8(PPh_3)_4(AuPR_3)_2](PF_6)_2$ were removed by soft bases such as halides or tertiary phosphines (Moehring, Fanwick, and Walton, 1987). This is the first report, however, of alkenes effecting the removal of a coinage metal from such a mixed metal compound.

The reaction of alkenes with $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ is also similar to the reaction of triethylamine with $[ReH_5(PPh_3)_3(AuPPh_3)]PF_6$ (Moehring and Walton, 1988). $[ReH_4(PPh_3)_3(AuPPh_3)_2]PF_6$, the product of the reaction of triethylamine with $[ReH_5(PPh_3)_3(AuPPh_3)]PF_6$, results from the loss of a hydride ligand as H^+ and the transfer of an $AuPPh_3^+$ fragment during the reaction. $[AgReH_4(PPh_3)_3]_2$, the product

of the reaction of alkenes with $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$, results from the loss of a hydride ligand as H^+ and the loss of an Ag^+ during the reaction. Both reactions, then, consist of the loss of H^+ and the loss or transfer of a coinage metal fragment when the mixed metal polyhydride compound is exposed to a nucleophile.

We attempted to determine the fate of styrene in its reaction with $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ by performing the reaction in $CDCl_3$ and monitoring the reaction mixture periodically by ^1H NMR spectrosocpy. The ^1H NMR spectra revealed only free styrene. We were unable to observe any resonances that might be attributed to chemicals such as bound styrene, ethyl benzene, or styrene oligomers. Thus, any of these other possible styrene derivatives which might have formed are formed in concentrations below the detection limit for our ^1H NMR spectroscopy

The ^1H NMR spectrum of $[AgReH_4(PPh_3)_3]_2$, as measured in CD_2Cl_2, consists of only two resonances. The phenyl protons resonate at 7.2 ppm and the hydride ligands resonate at -4.70 ppm. No resonances corresponding to either bound or free alkene are observed in the spectrum. Integration of the resonances corresponds to four hydride ligands for each three triphenylphosphine ligands. The hydride resonance appears as a complex symmetrical multiplet due to coupling to with ^{31}P, ^{107}Ag, and ^{109}Ag nuclei. The ^{31}P NMR spectrum of $[AgReH_4(PPh_3)]$, recorded in $CDCl_3$, consists of a singlet at 21.6 ppm. Again, no coupling is observed between rhenium bound phosphorous and silver isotopes. No evidence of PF_6^- was observed in the ^{31}P spectrum of this compound.

The Nujol mull infrared spectrum of $[AgReH_4(PPh_3)_3]_2$ exhibits only monosubstituted phenyl ring overtones in the metal-hydride stretching region. No absorption due to PF_6^- is observed. Because the compound is insoluble in any appropriate solvent, conductivity measurements were not attempted. The compound is, however, quite soluble in benzene, corresponding to the formulation of $[AgReH_4(PPh_3)_3]_2$ as a nonelectrolyte.

The determination that $[AgReH_4(PPh_3)_3]_2$ is dimeric in nature was made from molecular weight measurements. The molecular weight of $[AgReH_4(PPh_3)]_2$ was determined by the freezing point depression of a benzene/$[AgReH_4(PPh_3)_3]_2$ solution. The molecular weight was determined to be approximately 2000 g/mol. This corresponds to the formulation of the compound as $[AgReH_4(PPh_3)_3]_2$ rather than $AgReH_4(PPh_3)_3$. The most likely structure for this compound would be one in which the silver centers bridge two $ReH_4(PPh_3)_3$ fragments. Another compound which contains a silver atom bridge between two rhenium centers has previously been reported (Connelly, Howard, Spencer, and Woodley, 1984).

The cyclic voltammogram of $[AgReH_4(PPh_3)_3]_2$ consists of a single irreversible oxidation at +0.65 V versus Ag/AgCl. The shift in oxidation potential from the +1.70 V found for $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$ to the +0.65 V for $[AgReH_4(PPh_3)_3]_2$ is entirely consistent with the loss of positive charge that occurs at the rhenium centers during the reaction.

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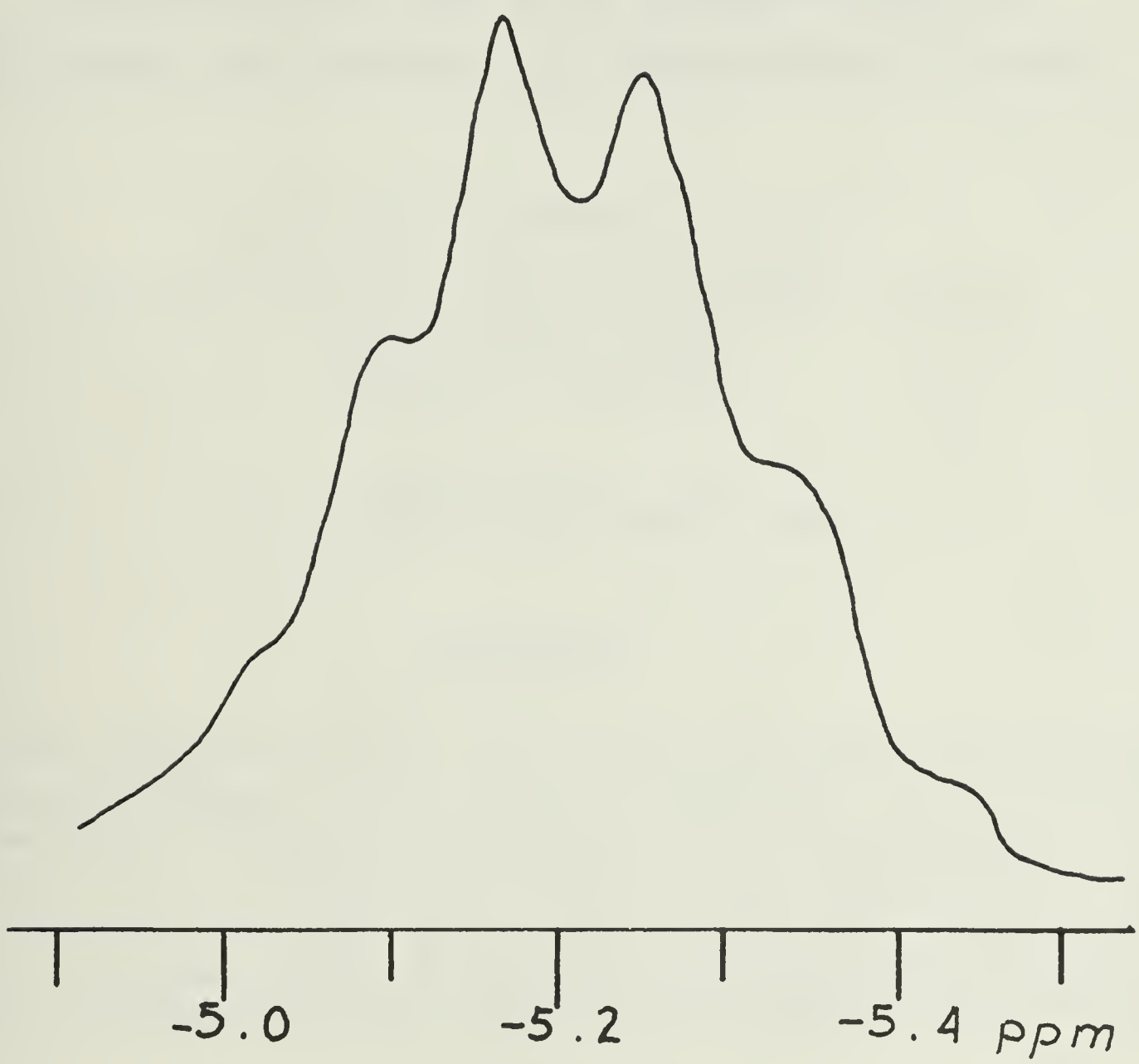
Figure 1. The ^1H NMR hydride resonance of $[Ag_2ReH_5(PPh_3)_3](PF_6)_2$.



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A Novel Pulsed Video Thermography Apparatus for the Quantitative Characterization of Material Flaws

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ABSTRACT

Pulsed Video Thermography (PVT) is an emerging nondestructive test method that offers inherent advantages over more conventional techniques. The PVT Laboratory of Southern Illinois University at Carbondale is one of the few research groups in the United States to have developed a novel PVT computer work station that utilizes simple off-the-shelf components with inexpensive liquid crystal technology. The system is user friendly, portable, and allows for automated thermal image capture. It represents a significant advancement toward the practical application of the method.

INTRODUCTION

Today's highly competitive global market has made the inexpensive, rapid, on-line non-destructive assessment of material integrity crucial to the economic survival of many companies. This is especially true of the composite materials industry where the prevention of catastrophic failure of aerospace or automotive structures is paramount to public safety. The traditional non-destructive testing (NDT) methods for the location and characterization of flaws and quality parameters are sometimes not physically or economically feasible. For example, X-ray NDT applied to carbon-carbon composites has the advantage of detecting internal flaws but buried delaminations are difficult to detect due to poor contrast between the fibers and matrix (Gardner, 1973) . Complex structures are difficult to test because access to two opposing surfaces is required. Cost is high and the method is safety intensive. Ultrasonic NDT yields good sensitivity and resolution of voids, cracks, and delaminations, but is time consuming and usually needs some type of surface coupling or liquid immersion (Vavilov, et al., 1993). Non-contact laser ultrasound is currently being developed. However, it is usually economically feasible only for high-priced products (Ashley, 1994).

The emerging method of Pulsed Video Thermography (PVT) can be used as a viable alternative or screening procedure for the traditional NDT methods. It can detect the

same type of defects but does not require two sided access, typically has a fast area scan rate, and can be non-contact. A test specimen is **pulsed** with a powerful externally applied heat source to create a traveling steep temperature gradient within the test specimen. Flaws or irregularities alter the flow of heat, producing temperature contrasts at the surface that are **video** captured via computer. **Thermography** techniques can then be applied to the surface image to characterize the flaw and predict performance capability. Possible limitations of PVT include the requirement of uniform surface heating and the need for greater computational speed/memory when defects are multi-dimensional.

The development of a PVT computer work station using off-the-shelf components would have the benefits of low cost, ease of use, portability, and flexibility of application. A few research groups outside of America are currently pursuing this avenue (Hobbs, 1992) using relatively expensive infrared temperature imaging. The PVT Laboratory of Southern Illinois University at Carbondale is one of the few groups in the United States to have developed a quantitative apparatus using low cost liquid crystal technology for automated thermal image capture.

METHODS AND MATERIALS

A schematic of the apparatus is given in Fig. 1. The equipment/software are relatively low cost, off-the-shelf items that are readily portable and well suited for plant operations.

The experimental procedure begins with the specimen surface facing the flash lamps being coated with a layer of temperature sensivtive liquid crystals approximately 0.02 mm thick. A 286 control computer then administers a short intense pulse of heat via a bank of lamps while simultaneously initiating the video camera to capture board system of the 486 computer. It does this through the use of a programmable relay card that has access to the computer time clock. The control computer then continues to oversee the capture of a set amount of image frames at predetermined times until the test is finished.

Once the experimental image frames are captured the pixel information that they contain is accessed by an image processing software package. Each pixel consists of red, green, blue (RGB) color values of the light reflected by the liquid crystals on the test piece surface. These RGB values are correlated to the surface temperature through a newly developed calibration scheme validated by the authors. Thus, each image produces a matrix of transient temperatures representing each position which is used to quantify the flaw characteristics via thermography.

RESULTS AND DISCUSSION

Kulkarni and Brady (1995) have developed a simple expression for estimating the time for an applied heat pulse to reach a defect at a given depth within a test piece. Table 1 lists their results for several common materials. This information can be used along with the PVT system data to compare the thermal response between flawed and benchmark specimens. The time at which the surface temperature image

of the defective specimen deviates from the standard can be directly related to flaw depth.

The previously described PVT apparatus has been successfully calibrated for the syncronization and control of the heat input and image capture. A new calibration technique has been used to correlate pixel RGB color data to temperature without the use of optical filters or observer judgement (Kulkarni and Brady, 1995).

Preliminary test results have demonstrated the predicted relationship between the thermal response of flawed specimens and defect depth. Fig. 2 compares the PVT acquired thermal response between defective and flawless plexiglas plates 152 mm x 152 mm x 6.35 mm in size. The defective plate had a 6.35 mm diameter hole drilled at its center to a depth of 1.8 mm below the viewed surface. A heat pulse lasting approximately 1.8 s was applied to both plates. From Fig. 2 it can be seen that the deviation between the thermal response of the two plates begins at about 2.5 s, which represents the time for the heat input to travel from the surface to the hole bottom. The analysis of Kulkarni and Brady (1995) given in Table 1 predicts a flaw depth of 1.7 mm when using a t_d time of 2.5 s. Hence, the novel PVT apparatus combined with numerical modeling leads to an error of only 6% in characterizing flaw depth. Detailed discussions of more comprehensive investigations will be the subject of future articles.

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Table 1. Thermal velocity analysis of transient thermography.

$$t_d \approx \frac{l_d^2}{\alpha} \quad , \quad t_{d,num} = C_0 \frac{l_d^2}{\alpha}$$

t_d = time for thermal front to reach defect

$t_{d,\,num}$ = numerical method t_d

l_d = surface depth of defect

α = thermal diffussivity

Material	α (m^2/s)	$C_0 = \frac{t_{d,num}}{t_d}$
Aluminum	7×10^{-5}	0.136
Fiberglass	4×10^{-7}	0.114
Particle Board	1×10^{-7}	0.112
Plexiglas	1×10^{-7}	0.105

Fig. 1. Pulsed video thermography test apparatus.

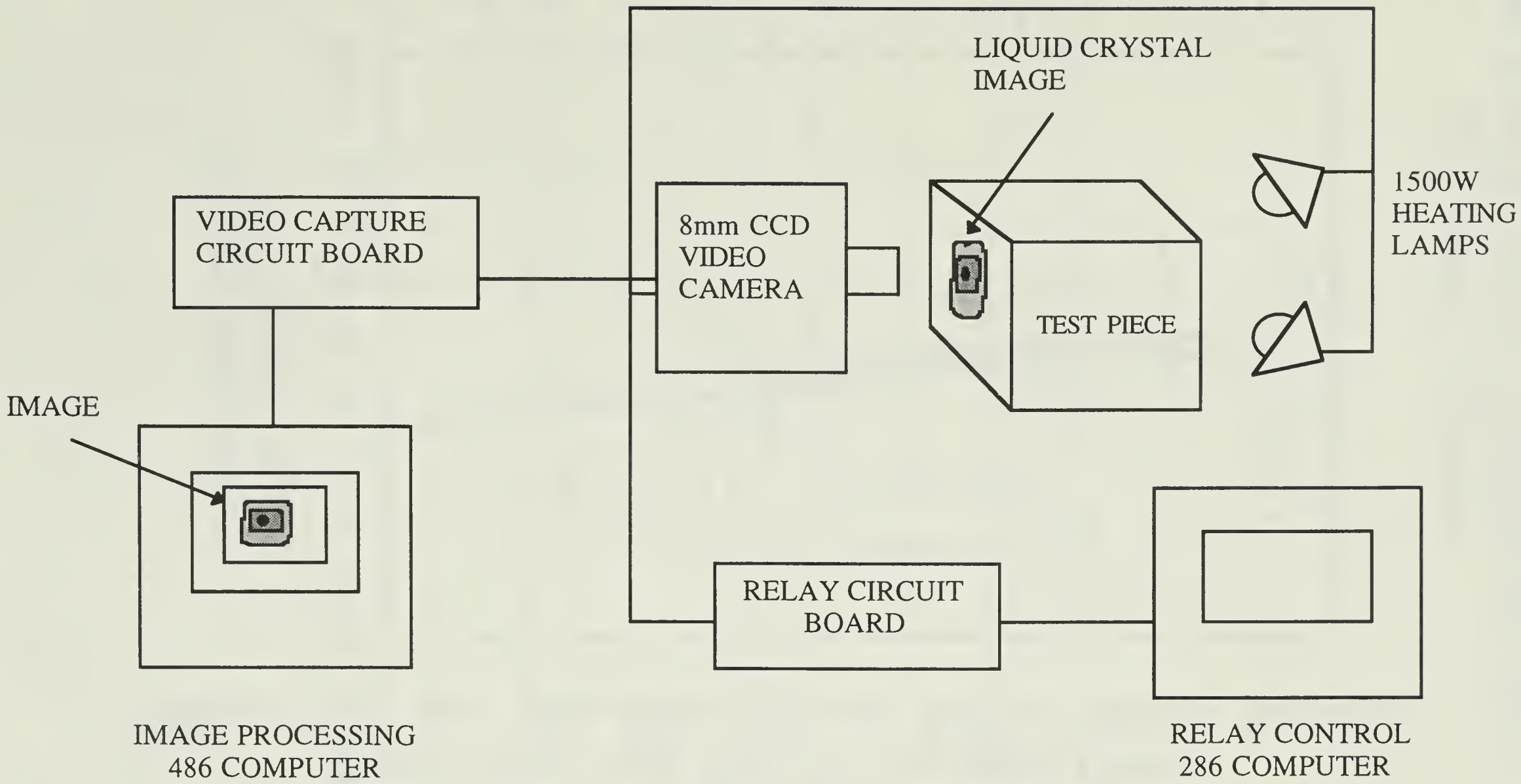
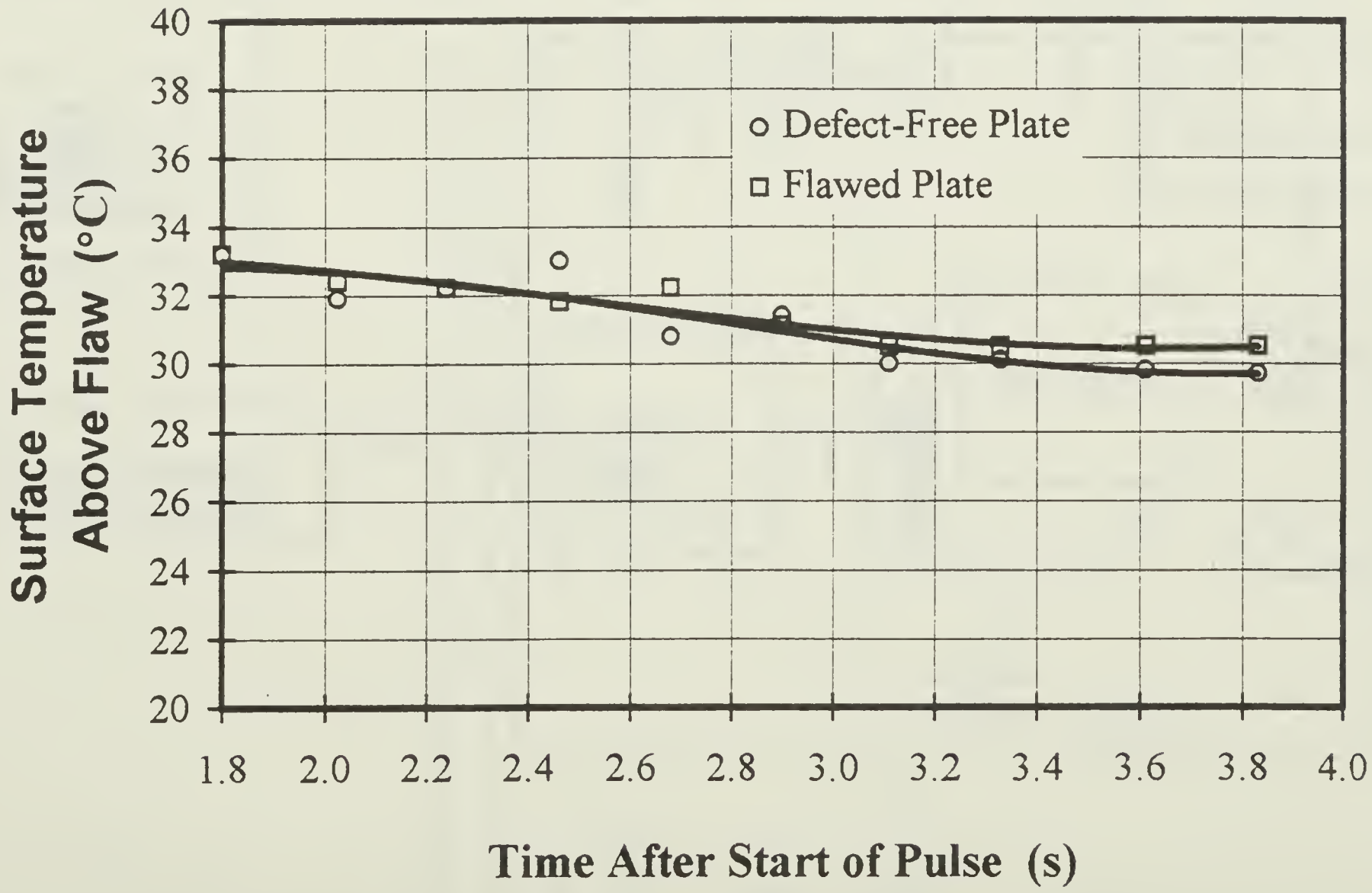


Fig. 2. The Effect of Time Upon Thermal Response
Defect-Free and Flawed Plexiglas Plates
Defect: 6.35 mm Dia. Hole 1.8 mm Below Viewed Surface



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An Unusual Color Pattern Variant in Cricket Frogs (*Acris crepitans*) from Southern Illinois

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ABSTRACT

A new color pattern variant is described in cricket frogs (*Acris crepitans*) from southern Illinois. Because of its geographically intermediate location within the species range, further studies of this color pattern may help elucidate the roles of natural selection versus chance in maintaining the balanced color polymorphism in *A. crepitans*.

The cricket frog, *Acris crepitans*, occurs from northeastern Mexico to southern Wisconsin in the U.S.A. and east to the Atlantic Coast. Thus, the species is adapted to diverse local temperature and moisture conditions ranging from semidesert to swamp. Terrestrial stages exhibit a genetically-based color polymorphism involving the vertebral stripe (Pyburn, 1961 a,b). The stripe can be various shades or red (red, brown, reddish brown), green, or gray (matching the non-red or non-green dorsum of the animal). The gray morph is consistently more abundant than the red or green morph in Illinois (Gray, 1983), Texas and Louisiana (Pyburn, 1961a), Indiana (Issacs, 1971), and other parts of the species range (Nevo, 1973). The background color in Illinois has been described as black, olive, or tan with green, olive, or rusty red markings (Smith, 1961).

Extensive sampling of *A. crepitans* from 32 localities in 25 counties (Gray, 1983) previously documented the frequency and distribution of the red, green, and gray vertebral stripe in Illinois. The background color of frogs in these samples was generally black, gray, or tan and sometimes had a slight greenish cast with small green spots. Samples taken in central Illinois (McLean County) over a three-year period were consistent with this description. However, samples taken over the same three-year period at a study site in LaRue Pine Hills swamp in southern Illinois (Union County) revealed some frogs where the entire dorsal surface was green. The color was much brighter than the normal green vertebral stripe or olive background color, and covered the head, body (including the vertebral stripe area), fore and hind limbs, and feet. The green pattern variant comprised about two percent of the population at this location, was not found anywhere else, and has not been reported previously.

The green color variant was found at a spring-fed pool, 0.8 km south of Winter Pond on the edge of the swamp. Emergent vegetation (watercress, *Nasturtium officinale*) and duckweed (*Lemna* sp.) covered the pool all year providing a constant green background. The pool was bordered by woods, interspersed with grasses, on each of two opposite sides. A dirt road and steep limestone bluff bordered the other two opposing sides. It is noteworthy that the site is geographically intermediate (i.e., north-east) between cricket frog populations in Texas where vertebral stripe color may be maintained by selective predation (Pyburn, 1961a) and populations in central Illinois where vertebral stripe may be maintained by chance primarily due to small effective breeding sizes (Gray, 1984).

Differential predator selection (Pyburn, 1961a), and physiological (Nevo, 1973) and/or behavioral (Wendelken, 1968) differences may exist among cricket frog color morphs in southern populations (i.e., in Texas). However, Gray (1977, 1979, 1983) found no morph-associated differences in predation susceptibility, shoreline distribution, or selected behavioral, physiological, and life history characteristics (dispersal, growth rates, survivorship) in northern populations (i.e., Illinois), even though occasional annual and geographic differences do occur among morph ratios (Gray, 1983). Whether the bright green color variant described here has any adaptive significance or is being maintained by recurrent mutation is currently unknown. Further studies of this color pattern variant may help elucidate the roles of natural selection versus chance in maintaining the balanced color polymorphism in *A. crepitans*.

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Food of the Evening Bat (*Nycticeius humeralis*) and Red Bat (*Lasiurus borealis*) from Southern Illinois

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ABSTRACT

Coleopterans represented the primary food item by volume for 13 evening bats (68.1%) and 7 red bats (68.7%) collected from July to September 1993 on Horseshoe Lake Conservation Area, Alexander County, Illinois. The single most important food for evening bats (23.5% of total volume) was the spotted cucumber beetle, a significant agricultural pest. This species made up only 7.9% of the food volume of red bats. The overall feeding overlap between these two species of bats appeared to be low.

INTRODUCTION

There is little information concerning feeding habits of the evening bat (*Nycticeius humeralis*), with the only published work from Indiana. The stomach contents of two evening bats were described by Ross (1967), and two others by Whitaker (1972). Whitaker and Clem (1992) examined 20 fecal pellets per week from May through October to determine foods eaten by evening bats at a maternity colony in Clay County, Indiana. Likewise, feeding habits of red bats (*Lasiurus borealis*) are poorly documented (Humphrey 1982). Whitaker (1972) reported on foods from 128 red bat stomachs from Indiana. Ross (1967) examined digestive tracts of 27 red bats from Indiana and Illinois. Here we report on foods consumed by evening bats and red bats captured from the same location and time period during a survey of bat fauna at Horseshoe Lake Conservation Area (HLCA).

MATERIALS AND METHODS

Study Area

The HLCA is located in Alexander County, in southern Illinois. It includes swamps of bald cypress (*Taxodium distichum*) and tupelo gum (*Nyassa aquatica*), bottomland hardwood forests dominated by an overstory of sweet gum (*Liquidamber styraciflua*),

slippery elm (*Ulmus rubra*), and pin oak (*Quercus palustris*), croplands of corn, soybeans, and winter wheat, and wetland areas dominated by emergent plants. Horseshoe Lake is a shallow (mean depth = 0.9 m), eutrophic lake about 796 ha in size (Brandon et al. 1994).

Bat Collection

Mist netting was done on 15 nights from 7 May through 10 September 1993 on 6 sites throughout HLCA. We used a layered mistnet 10 m high and 13.3 m long, with a pulley system to raise and lower it (Gardner et al. 1989). The net was in place by 2000 h and was left up each evening until about midnight, and was checked every 20 minutes. Age (juvenile or adult), reproductive condition, and body weight were determined for each bat. The bats were held separately in cloth bags for 0.5 h to obtain fecal pellets, marked on the back with a drop of red fingernail polish to determine recaptures, and released.

Food Analysis

The average percent volume (of each food type in the total sample) and percent frequency occurrence (percentage of individuals eating each food type) were estimated from fecal pellets using techniques discussed by Whitaker (1988). An index to resource overlap (MacArthur and Levins 1967) between the two bat species (*i* and *j*) was calculated as $\alpha_{ij} = \Sigma U_i U_j / \Sigma(U_i)^2$, where U is the proportional use of each food by each bat species, based on the most specific identifiable resource taxa. Because α is a ratio of resource use between both species (numerator) vs. individuals of the same species (denominator), values of $\alpha < 1$ suggest intraspecific interactions are stronger than interspecific factors.

RESULTS AND DISCUSSION

Of seven species of bats mist netted (Brandon et al. 1994), only evening bats and red bats were caught in large enough numbers to allow meaningful analysis of foods eaten. All evening bats (n = 13) and red bats (n = 7) from which fecal material was obtained were captured on one of four nights from 4 July through 8 September from one site. It was located 1.2 km S of Olive Branch, Alexander County, on Pigeon Roost Creek, a tree-lined stream corridor on HLCA. There were no recaptures for either bat species.

We identified only five orders of insects in the diet of evening bats from HLCA, with beetles comprising 68.1% of the material consumed (Table 1). The spotted cucumber beetle (*Diabrotica undecimpunctata*) was the single most important food of evening bats. This was also the case for evening bats in Indiana captured from August through October (Whitaker and Clem 1992).

Coleopterans comprised 68.7% of the food of red bats, with scarabaeids (June bugs) most of the total. Percentage volume and frequency of food types for red bats, however, was fairly distinct from that of evening bats (Table 1). Whitaker (1972) found lepidopterans were the primary food of red bats, followed by scarabaeids. One red bat had fed on crickets (Table 1), suggesting the possibility of ground foraging, although certain species of crickets are arboreal and could be taken by foliage

gleaning. Jackson (1961) and Whitaker (1972) also reported red bats feeding on crickets.

Overall, the amount of overlap in diets was limited, despite the fact that both bat species forage early in the evening (Layne 1958), and samples were collected at the same place and time period. The α - index for evening bats was 0.386 while that for red bats was 0.556, suggesting intraspecific overlap was more important than interspecific overlap between these species. Although the volume of beetles in red bats was essentially the same as in evening bats, red bats took only about one third the amount of *D. undecimpunctata* taken by evening bats during the period of this study. Limited forage overlap might be expected based on the mean length of the primary prey items bats consumed. The average length of *D. undecimpunctata*, the most common prey of evening bats in this study, is 5 mm (Swan and Papp 1972). June bugs, which were consumed 5.6 times more by red bats than by evening bats, average about 25 mm in body length. Ross (1961), based on limited data, reported red bats fed on small moths 10 to 16 mm long, but occasionally took moths as large as 30 mm. Similar data are not available for evening bats. Insect availability varies seasonally with resultant changes in the diet of bats (Whitaker and Clem 1992). Although our data are too limited both spatially and temporally to define these trends, they suggest an interesting line for future investigation of the feeding ecology of evening bats and associated species.

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Table 1. Frequency and total volume of foods of the evening bat (*Nycticeius humeralis*) and red bat (*Lasiurus borealis*) from Horseshoe Lake Conservation Area, Alexander County, Illinois determined by analysis of fecal pellets.

	Evening Bats		Red Bats	
	% Volume	% Frequency	% Volume	% Frequency
Coleoptera: Beetles				
Chrysomelidae				
Diabrotica undecimpunctata	23.5	38.5	7.9	28.6
Others	5.4	23.1	7.1	14.3
Scarabaeidae	8.8	23.1	49.4	85.7
Carabidae	8.8	23.1	4.3	14.3
Dytiscidae	5.4	7.7		
Others	16.2	53.8		
Homoptera: Leafhoppers and allies				
Cicadellidae				
Others	10.4	30.8	9.3	42.9
Paraphlepsius irroratus	1.9	7.7		
Delphacidae	0.4	7.7		
Hemiptera: True bugs				
Miridae	4.6	7.7		
Lygaeidae	1.5	7.7	4.9	42.9
Other	1.9	7.7		
Diptera: Flies	5.8	23.1		
Lepidoptera: Moths	5.4	15.4	15.7	71.4
Orthoptera: Grasshoppers and allies				
Gryllidae			1.4	14.3
TOTALS	100.0		100.0	

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The Pleasing Fungus Beetles of Illinois (Coleoptera: Erotylidae) Part III. Triplacinae. The Genus *Tritoma*.

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ABSTRACT

The Illinois fauna of the subfamily Triplacinae (Coleoptera: Erotylidae) includes 3 known genera: *Triplax* Herbst, *Ischyrus* Lacordaire and *Tritoma* Fabricius. The 10 species and subspecies of *Tritoma* known to occur in Illinois are treated in this paper. Two new records for Illinois are reported: *Tritoma tenebrosa* Fall and *Tritoma biguttata affinis* Lacordaire. Keys to the identification of adults, descriptions of each species, habitus drawings and distribution maps are provided. Fungal host relationships of each species are reported and discussed.

The family Erotylidae includes colorful fungus feeding beetles commonly called "pleasing fungus beetles". They are world-wide in distribution, with over 2000 described species. The family was comprehensively revised for North America by Boyle (1956). Of the 45 genera reported from the New World (Blackwelder 1945; Boyle 1956; Skelley 1993); 11 genera and 50 species are known north of Mexico (Boyle 1956, 1962; Goodrich & Skelley 1991a; Skelley 1993). Within the subfamily Triplacinae, 7 genera and 41 species occur north of Mexico. The purpose of this series of papers is to provide a complete list of the Erotylidae occurring in Illinois, keys and descriptions of adults of each species for their identification, distribution maps of their occurrence within the state, and descriptions of their biology and host relationships. Part I of this series covered the subfamily Dacninae (Goodrich & Skelley 1991b); Part II covered part of the Triplacinae, the genera *Ischyrus* and *Triplax* (Goodrich & Skelley 1993); this part covers the remaining Triplacinae, the genus *Tritoma*.

The family Erotylidae can be separated from other beetles by: their convex elongate-oval to ovoid shape; clavate-capitate antennae with 3-4 segmented antennal club; 5-5-5 tarsal formula, which is sometimes modified to a pseudotetramerous condition; glabrous body surface; closed procoxal cavities; well developed maxillary palps which are often expanded apically; and frequently bright color patterns. For a comparison to similar families and for a general description of their biology see Goodrich & Skelley (1991b). Our treatments of the host preferences of North American Erotylidae (Skelley, Goodrich & Leschen 1991; Goodrich & Skelley 1994) provide additional data on their biology.

The Erotylidae of North America are widely distributed over the continent and are generally restricted to moist woodland areas. No specimens have been seen from the Florida Keys, northern Canada, the Great Plains, or in deserts where trees and their host fungi are absent. Eastern and Midwestern species are generally distributed east of the 100th Meridian. Some species range further west where river valleys with forests are present. In Illinois, Erotylidae occur wherever hardwood forests persist, sometimes within urban settings.

MATERIALS AND METHODS

In addition to our extensive collecting, Illinois specimens of the subfamily Triplacinae were borrowed for study from 24 museums or private collections. A total of 9,708 specimens of *Tritoma* spp. were examined and identified; 4,096 of these were from Illinois. In our study of the Triplacinae we have followed the taxonomic treatment of Boyle (1956). The range of each species is based on specimens we have identified and the detailed records of Boyle (1956). Specimens studied are in the collections identified in the Acknowledgments, our personal collections, or those of our institutions.

Erotylids were collected in a wide variety of woodland fungi, in crevices under bark or in other retreats, and in a variety of insect traps (Malaise, flight-intercept, U-V light, and pitfall). This field work provided information on host relationships, as well as data on distribution and seasonal activity. Larvae collected in the field were reared to adults in the laboratory by placing the fungal host with eggs or larvae in a well ventilated, moist container with soil beneath the host fungus, where they were allowed to complete their development.

RESULTS

Three genera of Triplacinae (*Ischyrus* Lacordaire, *Triplax* Herbst and *Tritoma* Fabricius) are widely distributed in Illinois. *Ischyrus* and *Triplax* were treated in Part II of our "Erotylidae of Illinois" (Goodrich & Skelley 1993); *Tritoma* spp. are treated in this paper. Ten species and subspecies of *Tritoma* are found to occur in Illinois. The taxa are: *Tritoma angulata* (Say), *T. aulica* (Horn), *T. biguttata biguttata* (Say), *T. biguttata affinis* Lacordaire, *T. humeralis* Fabricius, *T. mimetica* (Crotch), *T. pulchra* (Say), *T. sanguinipennis* (Say), *T. tenebrosa* Fall, and *T. unicolar* (Say). Some of these species are common and widely distributed, while others are represented in Illinois by only one or two records.

Tritoma spp. were collected frequently in their host fungi and by Malaise trapping, less frequently in baited pitfall traps and only rarely in U-V Light traps. Adult and larval host fungi for *Tritoma* spp. are described in detail in Goodrich & Skelley (1994), although data are lacking for a few species.

Rearing of a number of *Tritoma* spp. was completed successfully in the laboratory on numerous occasions. In all cases, larval development was rapid, full grown larvae left the host to pupate in the soil of the rearing chamber, and adults emerged shortly after pupation. In all species reared, larvae completed development to adults in less than one month. Similar rapid development of larvae feeding on fleshy fungi is found in the genus *Triplax* (Goodrich & Skelley 1993) and in the staphylinid genus *Oxyporus* (Hanley & Goodrich 1994).

Key to Illinois Subfamilies of Erotylidae

Fourth tarsomere scarcely reduced, subequal in length to the third (Fig. 1); terminal segments of the maxillary palpi cylindrical (Fig. 3) ..... Dacninae
Fourth tarsomere strongly reduced, smaller than the bilobed third (Fig. 2); terminal segment of the maxillary palpi transverse or triangular (Fig. 4) ..... Triplacinae

The Triplacinae are usually considered more advanced than the Dacninae in possessing pseudotetramerous tarsi and highly specialized maxillary palpi in which the terminal segments are expanded, often very strongly. In contrast, the Dacninae have the more primitive 5-5-5 tarsal formula and cylindrical, acuminate terminal segments of the maxillary palpi.

We also find host associations to be more specific in the Triplacinae than in the Dacninae. While species of Triplacinae are commonly restricted to one genus or a few closely related genera of fungi (Goodrich & Skelley 1993; Goodrich & Skelley 1994), Dacninae often have a wide diversity of hosts (Goodrich & Skelley 1991b).

Key to Illinois Genera of Triplacinae

1. Eyes coarsely faceted and bulging; pronotum and elytra bearing a piceous or black pattern on a lighter background, pronotum with four black spots ..... *Ischyrus**
   Eyes finely faceted and small; pronotum and elytra not marked as above 2
2. Prosternal lines short, not extending in front of procoxal cavities (Fig. 5); body relatively elongate oval ..... *Triplax**
   Posternal lines long, either incurved anteriorly or meeting at prosternal apex (Fig. 6); body relatively broadly oval, tapering posteriorly ..... *Tritoma*

* These genera treated in the "Erotylidae of Illinois - Part II" (Goodrich & Skelley 1993).

Description of the Species

Genus *Tritoma* Fabricius

This is a genus of world-wide distribution with 105 species described (Boyle 1956), the great majority of which are native to the Old World. Only two species are Neotropical and 12 species and subspecies are recognized for America north of Mexico, all distributed east of the 100th Meridian (Boyle 1956; Goodrich & Skelley 1991a). We have records of 10 species and subspecies occurring in Illinois. Two new state records are reported in this paper.

Adults of the genus *Tritoma* can be separated from other United States Triplacinae by the finely faceted eyes, long prosternal lines surpassing the procoxal cavities anteriorly (Fig. 6), absence of a brush of hairs on the terminal segment of the maxillary palpi (present in *Triplax* spp.), and the generally ovoid body shape. The larvae are described by Lawrence (1991), Skelley (1988) and Peterson (1960).

Boyle (1956) divided the genus into two groups, species group *sanguinipennis* and species group *humeralis*. We find this arrangement appropriate, both on the basis of structure, as described in detail by Boyle, and from our comparative study of their fungal hosts (Skelley, Goodrich & Leschen 1991; Goodrich & Skelley 1994). The following key will aid in identifying the species of *Tritoma* of Illinois. Although characteristics of coloration are frequently used in the key, it should be noted that some species are quite variable in pattern and coloration, so species identified in the key should be confirmed by checking species descriptions.

Key to the Illinois Species of *Tritoma*

1. Epistomal apex either distinctly concave in a shallow V, or truncate, with submarginal striole evenly arcuate between antennal insertions (Figs. 8, 9); mentum pentagonal (Fig. 11) ..... Species group *sanguinipennis* 2
   Epistomal apex truncate to feebly arcuately concave, submarginal striole laterally angled (Fig. 10); mentum triangular (Fig. 12) ..... Species group *humeralis* 3
2. Epistomal apex distinctly concave in a shallow V, submarginal striole laterally angled (Fig. 8); prosternal lines not meeting anteriorly; elytra entirely reddish yellow ..... *sanguinipennis*
   Epistomal apex truncate, submarginal striole evenly arcuate (Fig. 9); prosternal lines long, meeting anteriorly, forming a triangle on the prosternum (Fig. 7); elytra partially piceous ..... *pulchra*
3. Body uniformly yellow-orange ventrally 4
   Venter piceous to black, at least on the medial aspects of the meso- and metathorax 6
4. Pronotum piceous to black; elytra with orange spots at the basal angles (Fig. 13) ..... *biguttata biguttata*
   Pronotum orange-red; elytra with or without orange spots 5
5. Elytra entirely piceous to black (Fig. 14) ..... *biguttata affinis*
   Elytra with orange-red spots at the basal angles (Fig.15) .....
   .....*Tritoma biguttata affinis* x *biguttata* (hybrid forms)

6. Elytra bicolored, orange-red and piceous to black 7
   Elytra entirely piceous to black 9
7. Elytra orange-red with piceous lateral margins (Fig. 17) ..... *mimetica*
   Elytra piceous to black with orange-red spots at the humeral angles 8
8. Pronotum orange-red ..... *aulica*
   Pronotum piceous to black (Fig. 16) ..... *humeralis*
9. Body not unicolorous; pronotum orange-red 10
   Body entirely piceous to black 11
10. Tibiae weakly dilated apically ..... *atriventris**
    Tibiae strongly dilated apically ..... *angulata*
11. Pronotal punctures large and sparse on disc, becoming much smaller and denser laterally; hind tibiae weakly expanded and rounded at apical angles (Fig. 18) ..... *unicolor*
    Pronotal punctures of almost uniform size, only slightly smaller and denser laterally; hind tibiae strongly expanded and angular at apical angles 12
12. Legs yellow, contrasting with darker body color; body shining above and below; small beetles, 3.0-4.3 mm long ..... *angulata*
    Legs dark, colored as body; body dull rather than shining; larger beetles, 3.8-5.7 mm long ..... *tenebrosa*

* No records yet from Illinois, but likely to occur here.

Species group *sanguinipennis*

This is the smaller of the two species groups, with two quite distinctive species found in North America; both are found in Illinois. The species are distinguished by a pentagonal mentum (Fig. 11), in contrast to the triangular mentum of species groups *humeralis* (Fig. 12). Boyle (1956) was able to recognize the relationship between these two species on the basis of their external structure, although he had little data regarding their fungal hosts. Our studies of the hosts of North American Erotylidae (Skelley, Goodrich & Leschen 1991; Goodrich & Skelley 1994) demonstrate that in contrast to species group *humeralis*, which largely are found in gilled fungi, the species group *sanguinipennis* are almost exclusively found associated with polypores.

***Tritoma sanguinipennis* (Say)**

DIAGNOSTIC DESCRIPTION. This species has a broadly oval body, pointed posteriorly, in addition to the concave epistomal apex (Fig. 8) and the pentagonal mentum (Fig. 11). The pattern of pigmentation is also distinctive in the genus *Tritoma*, with a black head and pronotum and entirely red-orange elytra and scutellum. Ventrally the head and thorax are black, with the abdomen orange. Overall length ranges from 3.17-5.04 mm.

RANGE. Eastern and central North America, ranging in the north from Maine and Quebec to Minnesota, Iowa and Kansas, and in the south from the Florida panhandle and Georgia to Arkansas. *Tritoma sanguinipennis* is widely distributed in Illinois, with specimens being found in all parts of the state (Fig. 19).

BIOLOGY. We have host records for 435 specimens (a large number of which were taken in Illinois), all collected from *Polyporus* spp. The most frequent records are from *P. arcularius* and *P. alveolaris*, with well over 100 specimens from each host.

We have reared the larvae on several occasions from *P. arcularius* and from one other unidentified species of *Polyporus* (see Goodrich & Skelley 1994 for details). Boyle (1956) recorded *Favolus canadensis* and *Hexagonia alveraris* from museum specimens. Moennich (1944) recorded a single specimen from *Amanita phalloides*, a record we treat with suspicion.

In our field work, we have found adult *T. sanguinipennis* in association with *T. humeralis* and/or *T. mimetica* on several occasions, and on one occasion (in *Polyporus radicatus*) with *Megalodacne heros*. Adult specimens of *T. sanguinipennis* have been taken in Illinois in every month from April to November. The immature stages have been described by Skelley (1988).

REMARKS. This species, like many species of *Tritoma*, is readily collected in Malaise traps. This trapping procedure allows the entomologist to get an excellent picture of adult seasonal activity, as well as adding distributional data.

SPECIMENS EXAMINED. We have examined a total of 1,108 specimens, of which 562 are from Illinois.

***Tritoma pulchra* (Say)**

DIAGNOSTIC DESCRIPTION. This species, broadly oval and pointed posteriorly as in *T. sanguinipennis*, is distinguished from all other North American *Tritoma* by the long prosternal lines which meet at the anterior margin of the prosternum (Fig. 7). Other diagnostic characters are the evenly arcuate submarginal striole of the epistomal apex (Fig. 9) and the pentagonal mentum (Fig. 11). The pronotum and scutellum are black and the elytra are red-orange with black at the lateral and posterior margins, sometimes creating a V-shaped red-orange sutural region. Ventrally, *T. pulchra* is uniformly dark, much darker than *T. mimetica*, the only species with similar dorsal pigmentation. Overall length ranges from 2.62-4.20 mm.

RANGE. Eastern and central North America, ranging in the north from New England, Nova Scotia and Quebec to Minnesota, South Dakota, Nebraska and Kansas, and in the south from northern Florida and Georgia to Oklahoma and Texas. Generally distributed in Illinois, although much less common than *T. sanguinipennis* throughout the state (Fig. 20).

BIOLOGY. We have reported *T. pulchra* from a variety of polypores in our treatments of the hosts of North American Erotylidae (Goodrich & Skelley 1994; Skelley, Goodrich & Leschen 1991). Weiss (1920) and Weiss & West (1920) reported this species from the polypore *Tyromyces chioneus* (under earlier names in the genus *Polyporus*), while Chantal (1979), Judd (1957) and Boyle (1956) also recorded it from *Polyporus* spp. Weiss (1924) reported *T. pulchra* from *Russula irrescens*(?). It is probable that in this case he confused *T. mimetica* with *T. pulchra*. *T. mimetica* is a superficially similar species which regularly feeds in a variety of gill fungi. In Illinois, we have five times taken *T. pulchra* from polypores in the genus *Oligoporus*, but never from *Russula* spp., despite examining thousands of specimens of *Russula* in the field and collecting hundreds of specimens of other species of *Tritoma* in these fungi.

Adult specimens of *T. pulchra* have been taken in Illinois in every month from March to October. The immature stages have been described by Weiss (1920), Roberts (1958) and Skelley (1988).

REMARKS. The extent of the black pigmentation on the elytra is variable. In some individuals the orange area is reduced to a triangular sutural area with extensive black lateral areas; in others the elytra are largely orange with the black areas restricted to the lateral margins, a pattern similar to that seen in *T. mimetica*. The pattern with the larger black areas occurs more frequently in southern Illinois. Further north, specimens generally have narrow black areas on the elytra, but are easily distinguished from *T. mimetica* by the uniformly black venter, the pentagonal mentum, and prosternal lines meeting at the anterior margin.

SPECIMENS EXAMINED. We have examined a total of 296 specimens, of which 74 are from Illinois.

Species group *humeralis*

This is the larger of the two species groups, with nine closely related species found in America north of Mexico, one of which includes two subspecies. All but two of these taxa are known to occur in Illinois. They are distinguished from species group *sanguinipennis* by a labium with a triangular mentum (Fig. 12) and a truncate epistomal apex with laterally angled submarginal striole (Fig. 10). In contrast to species group *sanguinipennis*, which are usually found in polypores, members of species group *humeralis* are typically associated with gilled fungi (Goodrich & Skelley 1994; Skelley, Goodrich & Leschen 1991).

***Tritoma biguttata biguttata* (Say)**

DIAGNOSTIC DESCRIPTION. This subspecies has a black head and pronotum and black elytra with triangular orange-red spots at the humeral angles. The elytral spots usually do not involve the humeri and meet or almost meet at the meson (Fig. 13). These markings, together with the yellow-orange venter, separate this species from the similar appearing *T. humeralis* and all other Illinois species of *Tritoma*. The subspecies *Tritoma biguttata affinis* is differently marked, with a red pronotum and uniformly black elytra. Overall length 2.63-4.50 mm.

RANGE. Northeastern and north central North America, ranging in the north from New England and Ontario west to Michigan and Illinois, and in the south from Virginia and North Carolina to Kentucky and southern Illinois, where this form intergrades freely with *Tritoma biguttata affinis*. In Illinois *T. biguttata biguttata* is the dominant form in the northern and eastern regions, intergrading with *Tritoma biguttata affinis* in the western and southern portions of the state (Fig. 21).

BIOLOGY. This subspecies has been collected in a variety of gilled fungi, although the majority of our records are from *Amanita* spp. See Goodrich & Skelley 1994; Skelley, Goodrich & Leschen 1991; Chantal 1979; Boyle 1956; Moennich 1939; and Weiss & West 1920, 1921, and 1922 for additional data. In Illinois we have numerous recent collections of *Tritoma biguttata biguttata* from *Amanita* spp. and a

smaller number from *Armillaria* spp. We have successfully reared the larvae in large numbers from *Amanita rubescens*.

In our field work, we have often found *T. buguttata* in large numbers, but usually not associated with other erotylids. On a few occasions we have taken adults in association with *T. humeralis* and/or *T. mimetica*. *Tritoma biguttata* is a summer beetle, as adults have only been taken in Illinois from June to early October. The immature stages for this subspecies are undescribed, although we have larvae associated with adults which we intend to describe in the future.

REMARKS. This form is conspecific with the differently marked *T. biguttata affinis*. Wherever these forms meet geographically an intermediate form with orange-red pronotum (as in *affinis*) and triangular orange-red spots on the elytra bases (as in *biguttata*) also occurs. This "hybrid" form was described by Casey (1916) as *Tritoma carolinae*. We have taken large numbers of the "hybrid" form together with even larger numbers of typical *T. biguttata biguttata* in Jackson County, IL. See Figs. 13-15 for a comparison of these forms and Goodrich & Skelley (1991a) for details of this synonymy.

SPECIMENS EXAMINED. We have examined a total of 1,938 specimens of this subspecies, of which 1,101 are from Illinois.

***Tritoma biguttata affinis* Lacordaire**

DIAGNOSTIC DESCRIPTION. This subspecies is different in appearance from *T. biguttata biguttata*, having an orange-red head and pronotum and uniformly black elytra (Fig. 14). Superficially *T. biguttata affinis* appears more like *T. atriventris*, which has a similar dorsal pattern of pigmentation, but *T. biguttata affinis* has a yellow-orange undersurface and moderately expanded hind tibiae, in contrast to the dark venter and slender hind tibiae of *T. atriventris*. Overall length 2.85-4.35 mm

RANGE. Southeastern and south central United States, ranging in the east from South Carolina south to Florida, and in the west from Texas north to Missouri, Nebraska, Iowa and western Illinois. Its range therefore lies south and west of *T. biguttata biguttata* and it intergrades freely with *T. biguttata biguttata* in North Carolina, northern Georgia, Tennessee and southern Illinois. In Illinois, specimens of this form are restricted to the southern and western portions of the state (Fig. 21).

BIOLOGY. This subspecies has been taken in a variety of gilled fungi. As with *T. biguttata biguttata*, it is most frequently found associated with *Amanita* spp., sometimes being collected in large numbers. We have reared the larvae to adults from several species of *Amanita*.

We have several records in the southern states of adults of this species in association with *T. atriventris*, a species closely allied to *T. humeralis*. Illinois collections of adults of *T. biguttata affinis* are restricted to July through September. In the southern states it may be active from April to November, although even there the greatest number of specimens are collected in the summer months. The larvae have been described by Skelley (1988).

REMARKS. As described earlier, we conclude that this form breeds freely with the typical form of *T. biguttata*. We have noted that wherever their ranges meet and both *T. biguttata biguttata* and *T. biguttata affinis* are present, hybrid specimens are also found. Furthermore, no series of specimens of the hybrid ("*carolinae*") form are found without one or both of the "parent" forms being present (Goodrich & Skelley 1991a).

SPECIMENS EXAMINED. We have examined a total of 995 specimens of *T. biguttata affinis*, of which 40 are from Illinois. In addition to these and the 1,938 specimens of *T. biguttata biguttata* studied, 182 specimens of *T. biguttata* "hybrids" have been examined, including 98 from Illinois.

***Tritoma humeralis* Fabricius**

DIAGNOSTIC DESCRIPTION. Generally similar to *T. biguttata biguttata* in pattern and pigmentation, with a black head and pronotum and black elytra with orange-red humeral spots. It is distinguished from *T. biguttata* by the piceous venter and the slender hind tibiae. The humeral spots are usually rectangular rather than triangular and extend laterally to include the elytral humeri, leaving a wider black region at the sutural area of the elytra than in *T. biguttata* (Fig. 16). Overall length ranges from 2.41-4.20 mm.

RANGE. Northeastern and north central North America, ranging in the north from New England and Quebec westward to Minnesota, Iowa, Nebraska and Kansas, and in the south from South Carolina through northern Georgia and Alabama to Arkansas. *Tritoma humeralis* is widespread and common in Illinois; we have collections from all parts of the state (Fig. 22).

BIOLOGY. Adults of *Tritoma humeralis* have been taken in a wider range of hosts than most species of *Tritoma*, being collected in several species of polypores in addition to gilled fungi (Goodrich & Skelley 1994; Skelley, Goodrich & Leschen 1991). The most favored hosts for the adults are *Polyporus* spp. and *Armillaria* spp. We have reared the larvae to adults in *Armillaria tabescens*, *Polyporus arcularius* and *P. squamosus*.

In our Illinois field work, we have taken adults of this species together with those of *T. mimetica*, *T. biguttata*, and/or *T. sanguinipennis*. Adults are active in Illinois from May to November, with the greatest numbers being taken in the summer months. The larvae are undescribed, although we have specimens preserved and intend to describe them in the future.

REMARKS. *Tritoma humeralis* is closely allied to *T. atriventris* and *T. aulica*, which agree exactly with *humeralis* in all aspects of external and internal anatomy, except for the pattern of pigmentation. It is quite possible that these three forms are conspecific (see further notes under *T. atriventris* and *T. aulica*).

Tritoma humeralis,like many other species of *Tritoma*, is particularly vulnerable to Malaise trapping. We can therefore get an excellent picture of adult seasonal activity through regular Malaise trapping in suitable habitat.

SPECIMENS EXAMINED. We have examined a total of 1,436 specimens, 905 of which are from Illinois.

***Tritoma atriventris* LeConte**

DIAGNOSTIC DESCRIPTION. Generally similar to *T. biguttata affinis* in pattern and pigmentation, with orange-red head and pronotum and uniformly black elytra. It is distinguished from *affinis* by its piceous venter and the slender hind tibiae. It is closely related to *T. humeralis*, which is identical in both external and internal morphology, but is easily separated from that species by its distinctive pattern of pigmentation. Overall length ranges from 2.69-4.35 mm.

RANGE. Southeastern and south central United States, ranging from Florida and Georgia west to Texas, Oklahoma, Arkansas and Missouri. We have no records from Illinois, but have seen five specimens from Shannon Co., MO and four specimens from St. Louis, MO; it seems likely that specimens will eventually be found in southwestern Illinois.

BIOLOGY. Adults of *Tritoma atriventris* are similar to *T. humeralis* in the wide range of host fungi they inhabit, including several *Polyporus* spp. in addition to a variety of gilled fungi (Goodrich & Skelley 1994; Skelley, Goodrich & Leschen 1991). Larvae have been reared in *Armillaria tabescens*, *Lentinus dentosis*, *Omphalotus olearius*, *Pleuteus* sp. and *Polyporus arcularius*, all common fungi in Illinois. In the Southeast, adults of *T. atriventris* are frequently found in association with *T. erythrocephala* Lacordaire, with which it may be conspecific. The larvae are described by Skelley (1988).

REMARKS. As noted earlier, *Tritoma atriventris* is closely related to *T. humeralis*. They differ only in color pattern and occupy separate ranges with a narrow range of overlap. In this area, a third form, *T. aulica* is found. *Tritoma aulica* is intermediate between *humeralis* and *atriventris* in its pattern (see notes under *T. aulica*).

SPECIMENS EXAMINED. We have examined a total of 1,079 specimens, but none yet from Illinois.

***Tritoma aulica* (Horn)**

DIAGNOSTIC DESCRIPTION. Intermediate in appearance between *T. humeralis* and *T. atriventris*, with the orange-red head and pronotum of *T. atriventris* and the black elytra with rectangular orange-red spots on the humeri as in *T. humeralis*. Otherwise similar in all morphological respects to *T. humeralis* and *T. atriventris*. From the dorsal aspect, *T. aulica* has some similarity to the form described by Casey (1916) as *T. carolinae*, but with a piceous venter and more slender hind tibiae. Overall length ranges from 2.83-4.07 mm.

RANGE. Occurring only in the area where the range of *T. humeralis* meets that of *T. atriventris*. Specimens are known from Kansas, Missouri, Illinois and Mississippi. One of the two Illinois specimens is labelled "S.Ill", the other labelled only "Ill."

BIOLOGY. No host data for this form are available, as few specimens have been collected by modern entomologists.

REMARKS. This species may well be a hybrid of *T. humeralis* and *T. atriventris*, as suggested earlier. The meager amount of collection data and small number of specimens seen makes this conclusion tentative; we will address this question in future papers.

SPECIMENS EXAMINED. We have examined 37 specimens, two of which are from Illinois.

***Tritoma mimetica* (Crotch)**

DIAGNOSTIC DESCRIPTION. Superficially similar to *T. pulchra*, with black head and pronotum, orange-red scutellum, and elytra orange-red with black lateral margins, the black lateral regions always narrow (Fig. 17). *Tritoma mimetica* is ventrally piceous on the meson of the pterothorax and abdomen, lighter laterally; as compared to the uniformly dark undersurface of *T. pulchra*. Mentum triangular and epistomal apex truncate, with submarginal striole laterally angled, as is typical for members of species group *humeralis* (Fig 10). Overall length ranges from 3.08-4.95 mm.

RANGE. Eastern and central North America, from Quebec and New York westward to Michigan, Iowa and Kansas in the north, and from Florida to Texas and Arkansas in the south. In Illinois, *T. mimetica* is widely distributed throughout the state. Although collection localities are scattered, it is probably more generally distributed (Fig. 23).

BIOLOGY. *Tritoma mimetica* is another species with a wide range of adult hosts, the most common of which are *Xerula* spp., for which we have 24 separate collection records amounting to over 100 specimens (Goodrich & Skelley 1994). *Xerula* was previously treated as *Oudemensiella* by mycologists, and was so cited in our earlier work (Skelley, Goodrich & Leschen 1991). Froeschner & Meiners (1953) also reported *T. mimetica* from *Oudemensiella radicata*. In Illinois we have also collected adults in *Armillaria mellea*, *Amanita vaginata* and three species of *Polyporus*. Larvae have been reared in *Boletus* sp., *Pluteus cervinus* and three species of *Polyporus*, but never from *Xerula* species, the most common adult host. One rearing observation is worthy of special note. On 16 Sept. 1991, one of us (M.A.G.) collected five adults of *T. mimetica* together with eight adults of *T. sanguinipennis* in *Polyporus alveolaris*. Eleven larvae found in the same sporocarp were reared, all of which were *T. mimetica*. As we have noted earlier in *Triplax* (Goodrich & Skelley 1991b), and for *Tritoma* (Goodrich & Skelley 1994), resource partitioning seems to be much stronger in erotylid larvae than for the adults. As mentioned here and in our comprehensive papers on the hosts of North American Erotylidae (Skelley, Goodrich & Leschen 1991; Goodrich & Skelley 1994), we have frequently collected adult *T.*

sanguinipennis in both *Polyporus arcularius* and *P. alveolaris*, but have only reared the larvae in *P. arcularius*. Oviposition may be seasonal, rather than host specific, in this case.

In our field work, we have taken adult *T. mimetica* together with adults of *T. sanguinipennis*, *T. humeralis* and *T. biguttata*. Adults have been collected in Illinois in every month from April to November. The immature stages are undescribed, although we have larvae associated with certainty to this species that we intend to describe in the future.

REMARKS. Originally thought to be an uncommon species, this species can be locally abundant. In addition to collection in host fungi, Malaise trapping has produced substantial numbers of specimens.

SPECIMENS EXAMINED. We have examined a total of 727 specimens, 390 of which are from Illinois.

***Tritoma angulata* Say**

DIAGNOSTIC DESCRIPTION. The first of three completely piceous to black species, *T. angulata* is distinguished by its yellow legs and strongly expanded tibiae. In contrast to *T. unicolor*, the pronotal punctures are of relatively uniform size and spacing. Although there is considerable overlap, *Tritoma angulata* body size averages smaller than the other "all black" species; overall length ranges from 2.63-4.35 mm. Although uncommon in Illinois, specimens with a red head and pronotum can be found, as indicated in the key.

It would be possible to confuse *T. angulata* with *Pseudischyrus extricatus*, a species which, although not recorded from Illinois, occurs in Indiana and Missouri and may eventually be found in southern Illinois. *Pseudischyrus extricatus* is similar in size, shape and pigmentation, but has coarse eye facets, as well as distinctive genitalia (see Boyle 1956 for details).

RANGE. Eastern and central United States, ranging in the north from New England west to Michigan, Iowa and Nebraska, and in the south from Florida west to Texas and Arkansas. One specimen labelled "Pasadena, Cal." is probably mislabelled. In Illinois, we have recorded *T. angulata* from eight locations in five counties (Fig. 25). This species will probably be found to be more generally distributed when its hosts are carefully examined (see Remarks below).

BIOLOGY. In recent years, we have established many host records involving hundreds of adult specimens. Virtually all of these records are from *Lactarius* (at least six spp.) and *Russula* (at least 10 spp.). In addition, we have reared larvae to adults from both *Lactarius* and *Russula* spp. (see Goodrich & Skelley 1994 for details). Moennich (1939) recorded *T. angulata* from two spp. of *Lactarius*. Adults have been collected in Illinois from late June through September. The immature stages are undescribed, but we have larvae preserved and intend to describe them in the future.

REMARKS. This is another species that is more common than its occurrence in museum collections would suggest. To illustrate: in examining over 60 national and regional insect collections, only five Illinois specimens of *Tritoma angulata* were found. In contrast, our own field work in Illinois produced 785 specimens between 1987 and 1993; most of these were collected in their host fungi. Although we have taken some specimens in our Malaise traps, this species appears less vulnerable to these traps than other *Tritoma* spp.

In the southern part of its range specimens of *T. angulata* with a red head and pronotum are more common. These specimens superficially resemble *T. atriventris*, but are easily recognized by their strongly expanded tibiae. In the north, all (or virtually all) specimens are uniformly piceous to black. In many intervening areas (i.e. Arkansas) we find a mixture of uniformly black and bicolored specimens. The differences are undoubtedly genetic and the populations are geographically separate, but the area with a mixture of both forms (intergrade zone) is wide. Therefore, we believe that the description of a subspecies for the "southern form" is not justified. We have recently taken four specimens of this bicolored form in east-central Illinois; in each collection the specimens were among large series of unicolorous specimens.

SPECIMENS EXAMINED. We have examined a total of 1,316 specimens, 790 of which are from Illinois.

Tritoma unicolor **(Say)**

DIAGNOSTIC DESCRIPTION. *Triboma unicolor* is uniformly piceous to black above and below, the legs almost as dark as the body, in contrast to the yellow legs of *T. angulata*. The pronotum is unique in the genus *Tritoma*, with large, sparse punctures on the disc, smaller and denser punctures laterally (Fig. 18). The tibiae are less dilated apically than in either *T. angulata* or *T. tenebrosa*. *Tritoma unicolor* is larger in size than *T. angulata*; overall length ranges from 3.31-5.63 mm.

RANGE. Eastern and central North America, ranging in the north from New England and Ontario west to Minnesota, Iowa and Kansas, and in the south from Georgia west to Louisiana and Oklahoma. In Illinois we have recorded *T. unicolor* from 16 widely scattered localities (Fig. 25).

BIOLOGY. We have recorded *T. unicolor* from *Omphalotus illudens* in Illinois, and have numerous records from *Omphalotus olearius* from other states (these fungi were almost certainly *O. illudens*, as mycologists now believe that *O. olearius* is exclusively an Old World species). Boyle (1956) reported *T. unicolor* from *Caluatia craniiformis*, *Hypoloma* sp. and *Clitocybe illudens* (now called *Omphalotus illudens*). Large numbers of larvae have been reared to adults in *O. illudens* in Arkansas by R. A. B. Leschen. Adults have been collected in Illinois from May to October. The immature stages were illustrated by Böving & Craighead (1931).

REMARKS. Despite the large number of collection localities recorded, this species is relatively uncommon in Illinois, although it can be locally common elsewhere.

SPECIMENS EXAMINED. We have examined a total of 580 specimens, 77 of which are from Illinois.

***Tritoma tenebrosa* Fall**

DIAGNOSTIC DESCRIPTION. A large, uniformly dark species of *Tritoma*, with strongly dilated tibiae, the hind tibiae with the outer apical angles sharp, almost right-angular. It is distinguished from *T. angulata* by the dark colored legs, dull appearance and relatively large size. It is distinguished from *T. unicolor* by the strongly dilated tibiae and the uniformly punctate pronotum. Overall length ranges from 3.80-5.66 mm.

RANGE. Known from a few widely scattered localities in eastern and central United States; ranging in the north from New York west to Illinois, and in the south from Florida west to Mississippi. This species is a new record for Illinois; the westernmost previous record is from Pennsylvania (Boyle 1956). Our only records from Illinois are two specimens from Cook County in the Field Museum of Natural History.

BIOLOGY. We have no host data for this species and would like to see voucher specimens from any fungal host.

REMARKS. A "rare" species, but one easily confused with *T. unicolor*. Specimens may be misidentified in collections.

SPECIMENS EXAMINED. We have examined a total of 14 specimens, two of which are from Illinois.

This is the fourth in a series of papers describing the Erotylidae of Illinois. The 10 species and subspecies of *Tritoma*, plus the addition of *Microsternus ulkei* (Crotch), recently discovered to occur in Illinois (Goodrich 1994), brings the total number of species and subspecies of Erotylidae known to occur in Illinois to 23. We would be pleased to examine and identify any New World members of the family to add to our seasonal and distributional data.

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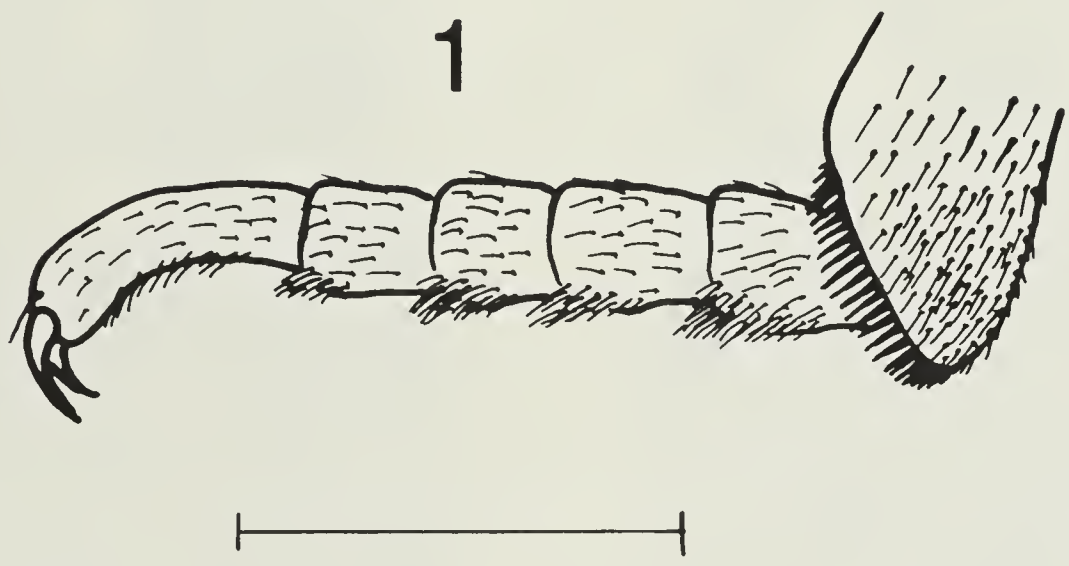
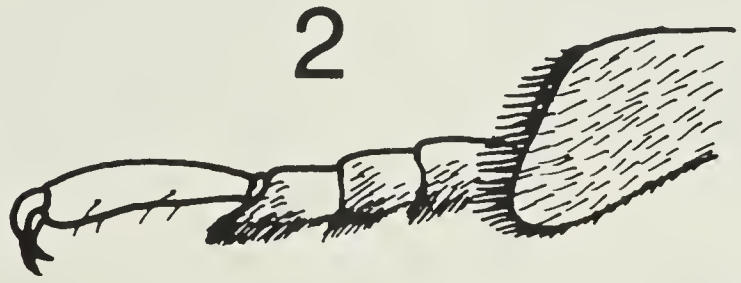
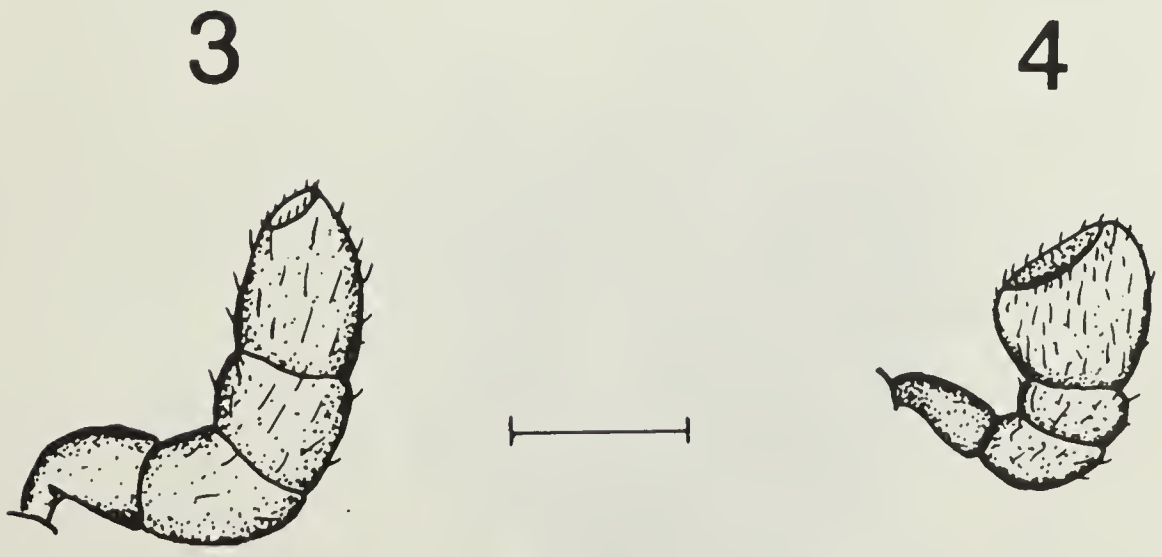
Figs. 1-2 Right metatarsus of aduls. 1. Dacinae - *Megalodacne fasciata* (Fabricius). 2. Tripacinae - *Ischyrus quadripunctatus* (Oliver). Line = 1.00 mm.

Figs. 3-4 Left maxillary palp of adult. 1. Dacninae - *Megalodacne fasciata* (Fabricius). 2. Triplacinae - *Ischyrus quadripunctatus* (Oliver). Line = 0.25 mm.



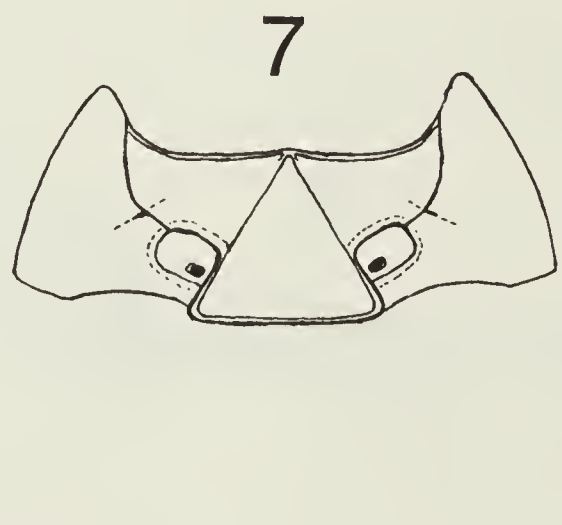


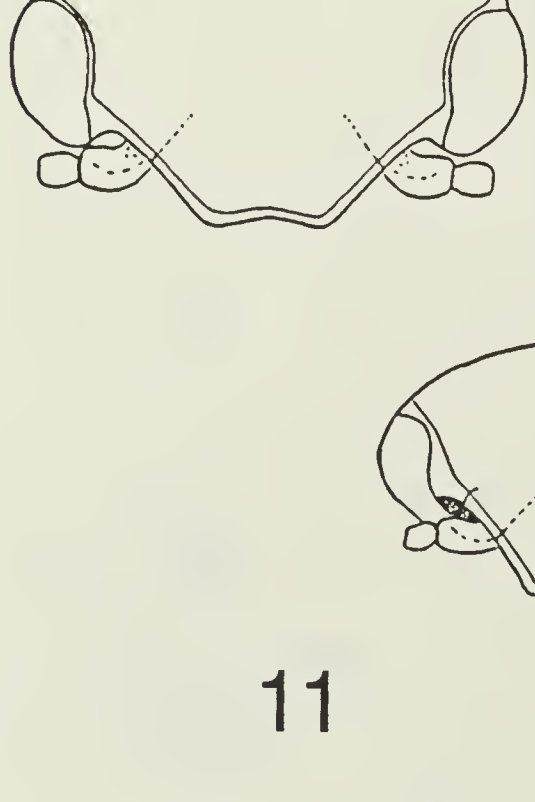


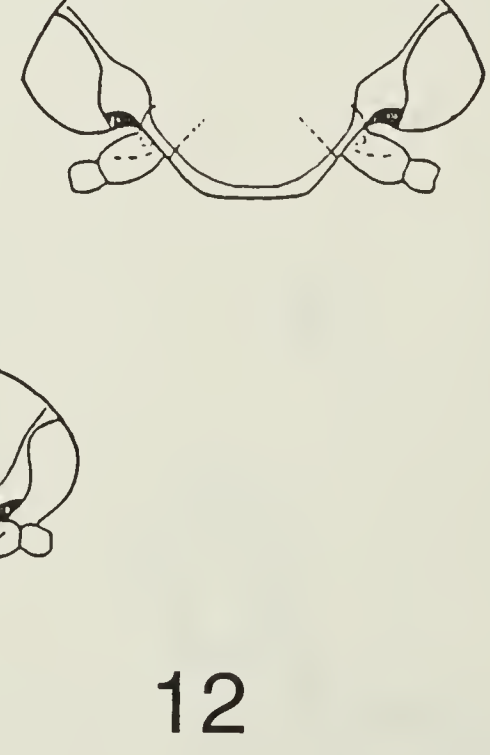
Figs. 5-7 Ventral view of prothorax. (Redrawn from Boyle 1956) 5. *Triplax frosti* Casey. 6. *Tritoma biguttata* (Say). 7. *Tritoma pulchra* (Say).

Figs. 8-10 Anterodorsal view of head without mouthparts. 8. *Tritoma sanguinipennis* (Say). 9. *Tritoma pulchra* Say. 10. *Tritoma humeralis* Fabricius.

Figs. 11-12 Ventral view of labium. 11. *Tritoma sanguinipennis* (Say). 12. *Tritoma unicolor* Say.







Figs. 13-15 Dorsal habitus of *Tritoma biguttata* (Say) sspp. 13. *Tritoma biguttata biguttata* (Say). 14. *Tritoma biguttata affinis* Lacordaire. 15. *Tritoma biguttata* "hybrid". Line = 2.00 mm.

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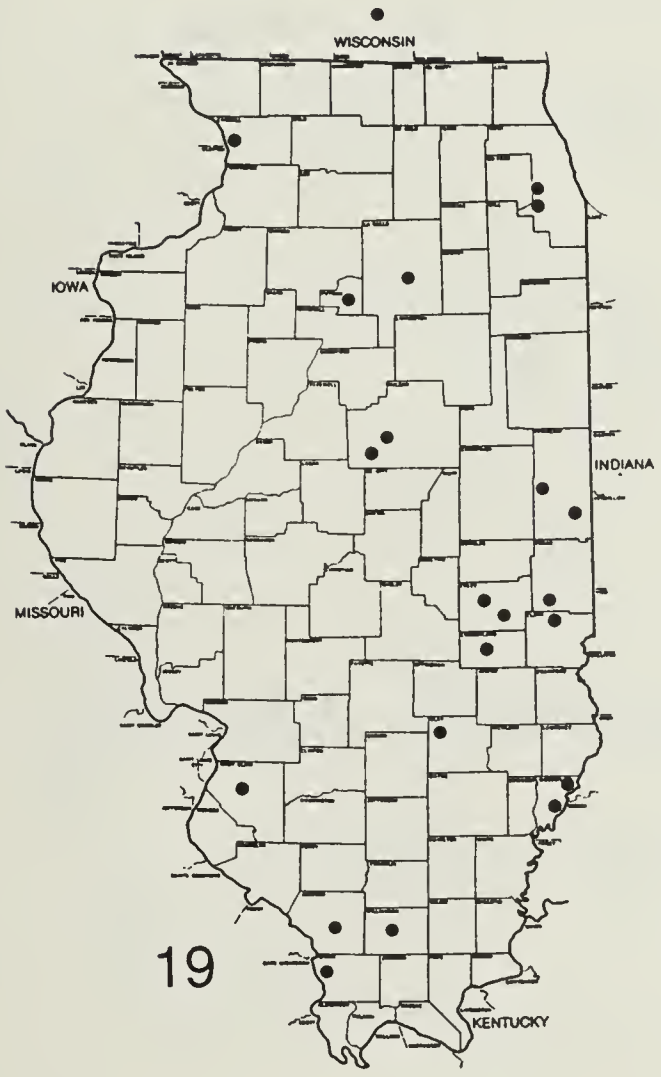
Fig. 16 Dorsal habitus of *Tritoma humeralis* Fabricius. Line = 0.66 mm.

Fig. 17 Dorsal habitus of *Tritoma mimetica* (Crotch). Line = 1.00 mm.

Fig. 18 Dorsal habitus of *Tritoma unicolor* (Say). Line = 1.00 mm.

Figs. 19-21 Distribution in Illinois of *Tritoma*. 19. *T. sanguinipennis* (Say) 20. *T. pulchra* Say. 21. *T. biguttata* subspecies. ● = *Tritoma biguttata biguttata* Say. ■ = *Tritoma biguttata affinis* Lacordaire. ▲ = *Tritoma biguttata* "hybrid" populations.



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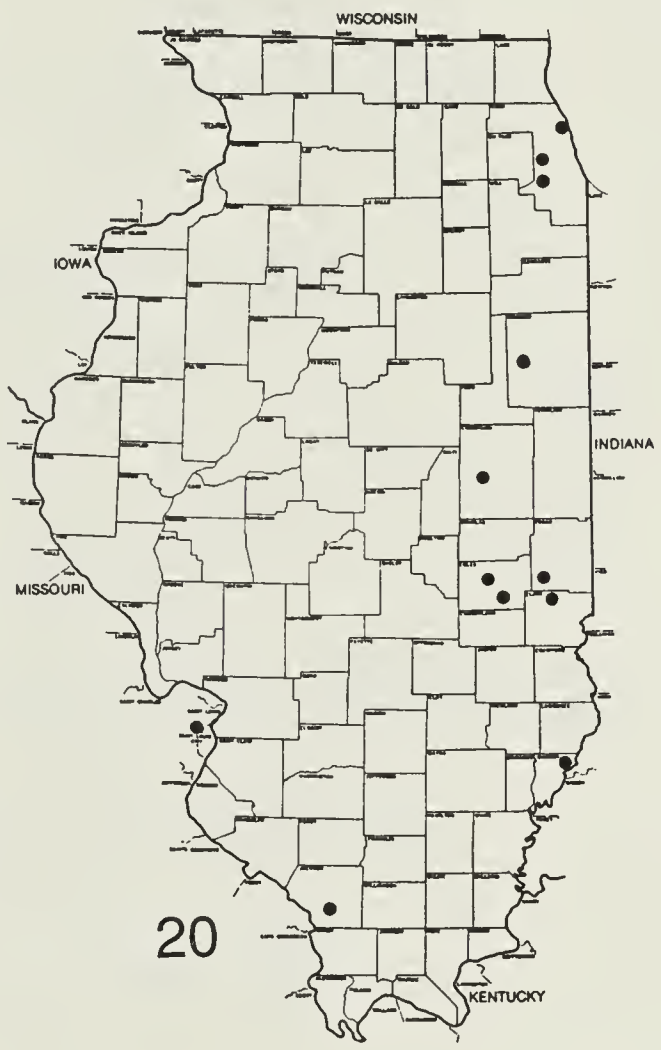

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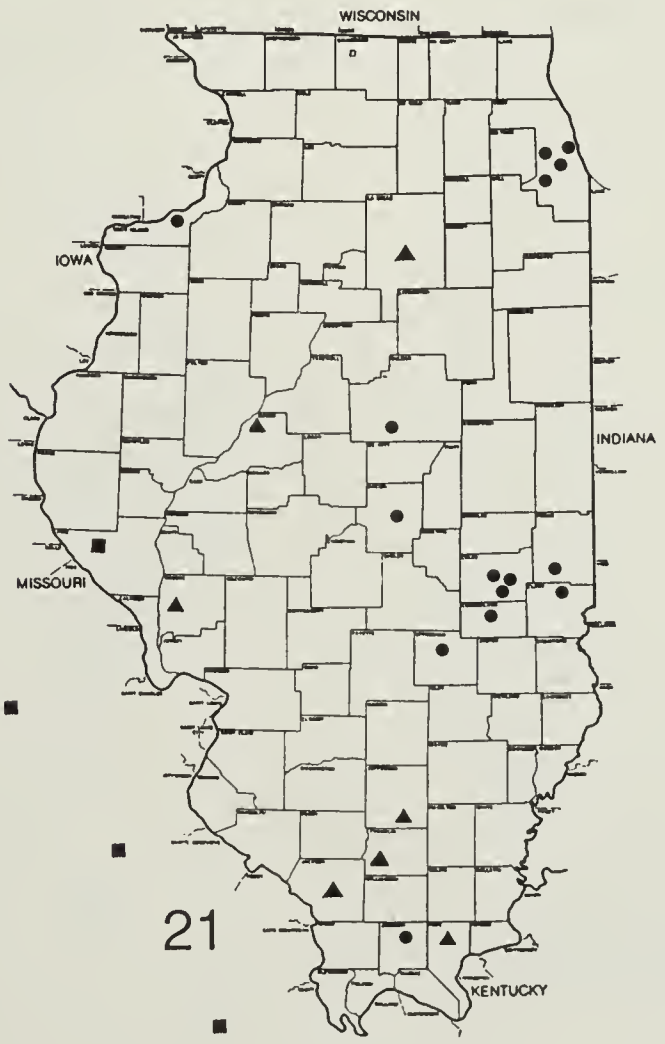

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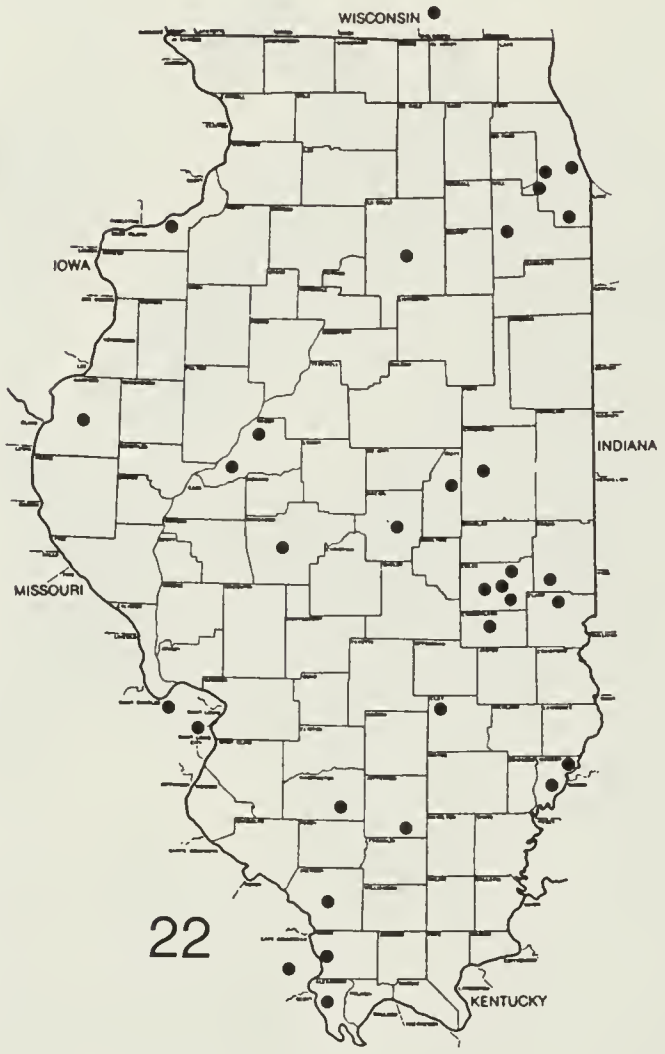
Figs. 22-25 Distribution in Illinois of *Tritoma*. 22. *T. humeralis* Fabricius. 23. *T. mimetica* (Crotch). 24. *T. angulata* Say. 25. *T. unicolor* (Say).



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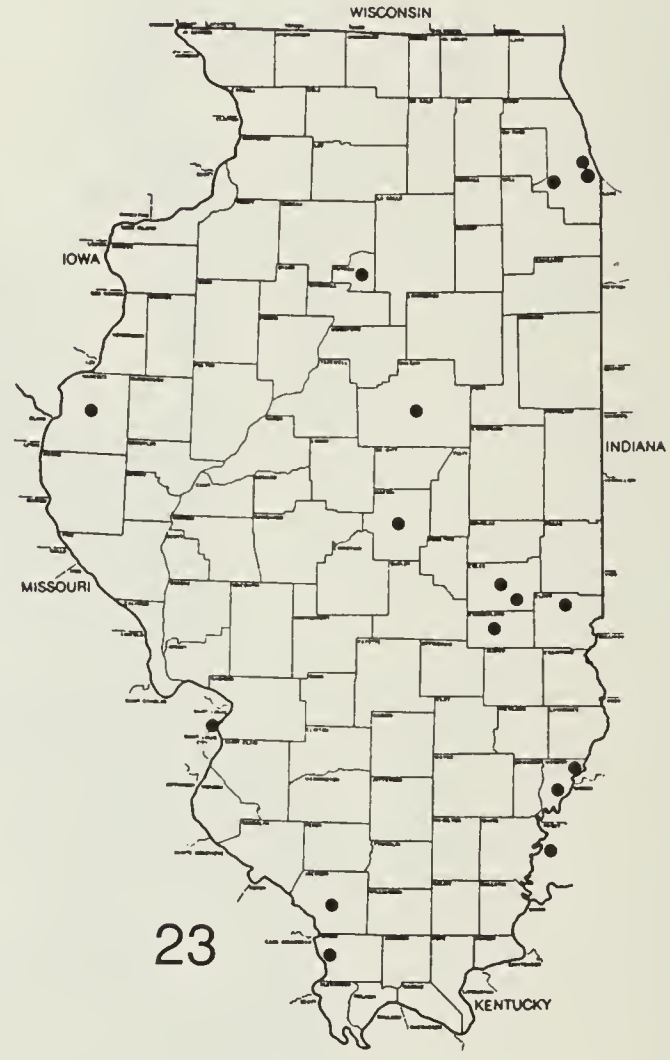

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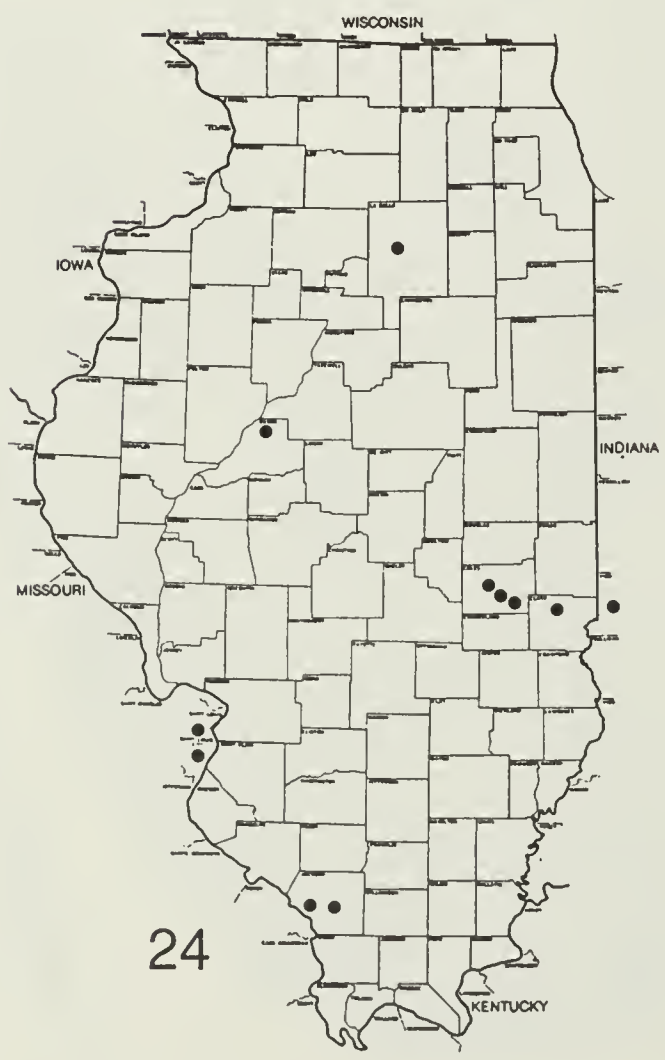

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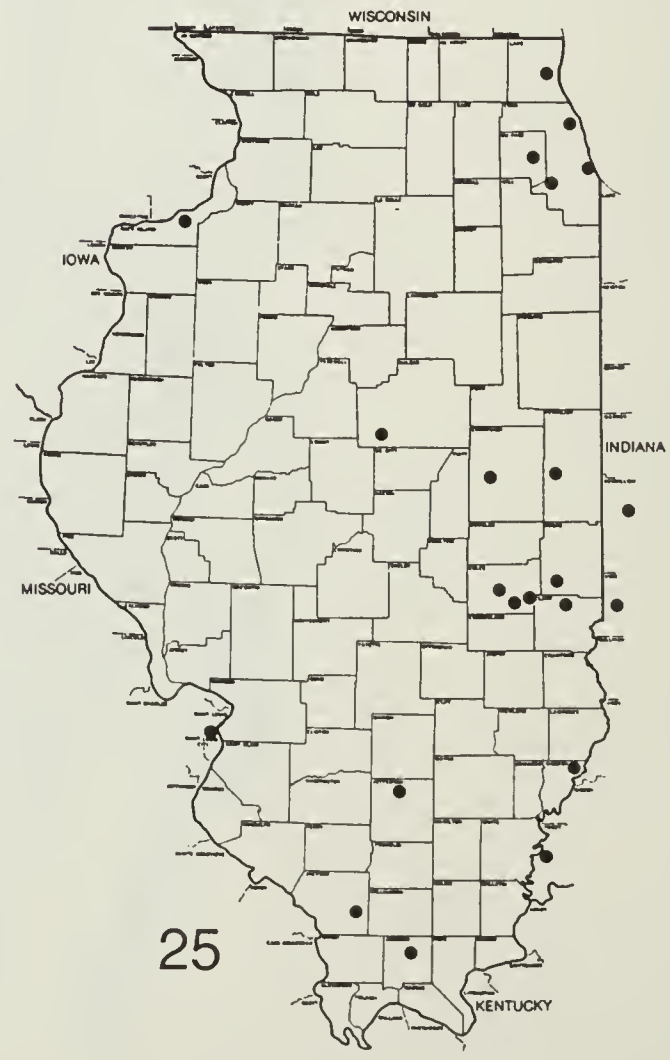

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